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Woods Hole Oceanographic Institution

PROCEEDINGS OF A WORKSHOP ON COASTAL ZONE RESEARCH IN MASSACHUSETTS (NOVEMBER 27-28, 1978)

by

David G. Aubrey

April 1979

TECHNICAL REPORT

Prepared for the Department of Commerce, NOAA Office of Sea Grant under Grant 04-8-M01-149 and the Institution's Marine Policy and Ocean Management Program.

WOODS HOLE, MASSACHUSETTS 02543

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Approved for Distribution: John I. Ewing

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Department of Geology & Geophysics

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APPENDIX 1 - Workshop Participants

I. SUMMARY

A Workshop on Coastal Zone Research held on 27 and 28 November, 1978, at Woods Hole Oceanographic Institution, brought together fifty researchers actively studying physical processes in the Massachusetts coastal zone (Appendix 1). Presentations were given by nearly half of the participants to acquaint other researchers with their past, present, and future research interests. Summaries of the presentations are included in Appendix 3. Although the scope of the workshop was narrow, emphasizing only selected aspects of coastal zone research, it represented an important attempt to assess our knowledge of physical processes in the nearshore, and to encourage cooperation and communication between scientists.

Two sets of recommendations evolved from the workshop. The first set recommends ways to facilitate scientist - user communication, and provide more rapid dissemination of coastal research results. The second set describes areas of future research in the Massachusetts coastal zone. Neither of the two sets of recommendations is comprehensive: they reflect primarily the opinions and judgements of the workshop participants.

Because of the interest expressed by the participants, the workshop will be held on an annual basis until the need for such meetings disappears. Future workshops may have specific goals, e.g. preparation of coastal erosion maps or historical shoreline change maps. Future meetings may also have more state, federal, and local governmental participants in an effort to foster scientist - user communications.

The workshop was co-sponsored by the Woods Hole Sea Grant Program and Woods Hole Oceanographic Institution. The Woods Hole Sea Grant Program has offered to co-sponsor future Workshops on Coastal Zone Research as part of their continued interest in the Massachusetts coastal zone.

II. INTRODUCTION

On November 27 and 28, 1978, a Workshop on Coastal Zone Research in Massachusetts was held at Woods Hole Oceanographic Institution in Woods Hole, Massachusetts. Approximately fifty coastal zone researchers participated (Appendix 1) from all over Massachusetts, most of whom actively study physical processes in the nearshore zone. The workshop was co-sponsored by the Woods Hole Sea Grant Program and Woods Hole Oceanographic Institution.

The workshop was designed to fulfill two primary goals:

(1) To acquaint investigators with the past, present and future research interests of other Massachusetts and nearby coastal zone researchers, thereby facilitating free flow of information and fostering cooperation between researchers.

(2) To evaluate potential communication between researchers and coastal planning efforts within state, federal, and local agencies. The data requirements of governmental agencies can be compared with the available scientific studies, resulting in a candid assessment of deficiencies in our knowledge of the Massachusetts coastal zone.

The first goal was successfully attained by means of the workshop. Most workshop participants presented a short discussion of their research efforts, acquainting others with their primary research interests. In addition to the presentations, the speakers were requested to submit summaries of their talks for publication. These are included in Appendix 3. The individual presentations combined with the discussion session on the second day effectively encouraged communication between researchers.

In an effort to satisfy the second goal, most of the second day of the workshop was devoted to a discussion of the needs of state, federal and local agencies in the coastal zone and how to alleviate these needs. This required an assessment of our present knowledge as well as an outline of the major deficiencies in our understanding of the coastal zone. The results of these discussions are included in a later section of this report.

The workshop participants were primarily active Massachusetts coastal zone researchers . Representatives from state, federal and local agencies were invited, however, to help determine their requirements for coastal zone research. Management representation was not comprehensive since the major intent of the workshop was a candid evaluation of our scientific knowledge of physical processes in the coastal zone; this evaluation could then serve as a management tool for governmental agencies. Future workshops might more heavily emphasize participation by governmental representatives to encourage scientist-management communication.

The workshop participants strongly expressed their interest in having a yearly Workshop on Coastal Zone Research in Massachusetts. The consensus was that the workshop is an effective forum for exchanging and discussing research interests, methods and goals. The Woods Hole Sea Grant Program has demonstrated its interest in coastal zone problems, and is willing to co-sponsor next year's workshop. Considering these interests, an effort will be made to organize another workshop in late 1979 - early 1980. If sufficient interest still exists, the workshop may become an annual event. Future participation by other researchers is encouraged.

Several options for future workshops were discussed. The present workshop neglected multi-disciplinary coastal zone interchanges in an effort to produce a manageable working unit with common interests. Consequently, chemists, biologists and other nearshore scientists were not asked to attend. A suggestion was made that an interdisciplinary workshop in following years might further advance interchange of coastal zone information. The obvious concession in such a workshop is the working group becomes less manageable, which could inhibit effective exchange of ideas. This option will be seriously considered when planning future workshops.

Another possibility is the inclusion of more management personnel, including planners, politicians and lawyers. Certainly, if the primary purpose of the workshop were solely to disseminate our knowledge and ideas to state, federal and local agencies, more of these people should be included. However, if a primary purpose of the workshop were to encourage communication between scientists, and candidly assess our research goals and interests, then the primary participation should be among scientists. There are partially conflicting goals here: a candid scientific evaluation does not blend well with a scientist - decision maker interchange. Future participation will be decided only after careful consideration of ideas expressed during this workshop, and after future ideas from the participants have been solicited and carefully considered.

Alternatives to holding one large workshop include: (a) hold separate workshops for scientific purposes and for scientist - management interchange, and (b) perhaps include management and non-scientists in the late stages of a scientific workshop, for example during the final two days of a four-day workshop. All options will be carefully considered before making a decision for future workshops. Enough interest has been expressed on the inter-scientist communication that this will still be an integral part of future workshops.

III. WORKSHOP FINDINGS

The second day of the workshop was devoted primarily to a discussion session in an effort to satisfy the second workshop goal. The discussion centered around two primary topics: (A) What are the needs of state, federal and local groups and how can the scientific community communicate with these groups; and (B) What are the major deficiencies in our knowledge of the coastal zone, and what are their priorities. Each of these topics is covered in outline form in the following sections. Although not complete, the outlines strongly suggest ways to promote scientist - management communications, and provide guidance for future research efforts in the Massachusetts coastal zone. In these summaries, the author has undoubtedly interpreted the discussion session according to his biases; the outlines therefore may not precisely represent the consensus of the entire working group. The author accepts the responsibility for any errors or misinterpretations contained in the outlines.

A. Resolving Communications and Data Exchange Problems

Following is a partial list of options suggested by the workshop participants to both encourage scientist-to-scientist data exchange, and to expedite the transfer of scientific knowledge to user groups who are required to oversee and administer the coastal zone in Massachusetts. It is widely acknowledged that the latest scientific results are not always used in policy and management decisions; the blame for this falls on both the scientific investigator who may not know how to disseminate the information in a popular format, and on the user group who may not have the time, resources, or background to search for the scientific results relevant to a particular problem. The following suggestions should help alleviate these difficulties.

1. Use of Massachusetts Coastal Zone Management (CZM) as an Intermediary

The Massachusetts Coastal Zone Management Act has established a managerial structure for treating coastal zone problems (including, but not limited to, physical processes), presenting a promising possibility for interchange of information. CZM personnel must be cognizant of scientific research, while simultaneously educating local communities about ways to resolve their coastal problems. CZM is therefore a logical interface between the scientist and the local community, providing both basic results and interpretation of scientific studies. Three primary options were suggested for making CZM an efficient intermediary, without significantly burdening CZM personnel:

(a) Use mailing lists to inform the scientific and lay communities about CZM programs. Two mailing lists are suggested: one to the scientific community to inform them of CZM projects, and a second to the lay community to inform them of local scientists who may be helpful in evaluating, and perhaps solving, their coastal problems. The scientific mailing list might describe the CZM projects and their status, and could serve as a Request for Proposals (RFP) if appropriate. The mailing list to the lay communities would allow them to contact nearby scientists to help analyze their problems. The scientist, although not bound in any way, may be able to help the community by formulating the coastal problem in a scientific framework, guide the local community in solving the problem, or perhaps even serve as a project overseer, to insure the problem is approached in a reasonable manner. This would in no way conflict with industry, since the scientific community and industry have different types of services to offer.

(b) Encourage CZM educational programs with the local communities by personnel familiar with past and recent coastal zone research. Since this is done to a certain extent now, this suggestion would serve only to strengthen and expand that program.

(c) Encourage basic, scientific research on problems in the Massachusetts coastal zone which have widespread application. An example might be the study of the Massachusetts wave climate, or the synthesis of offshore current information applicable to the study of pollutant dispersal or biological advection.

2. Use of Advisory Services

Interchange of information between the scientist and the coastal manager could be enhanced by establishing advisory services through some of the scientific institutions in the state. This might take the form of a public relations officer who is well-informed about coastal research, or a full-time staff member actively distributing scientific results. An example of the latter is the Sea Grant Program at the Massachusetts Institute of Technology, which has established a full-time advisory service for local needs. The Woods Hole Sea Grant program is planning to add a marine assistance person to help communicate its work to the local population. Sea Grant is a natural participant in the advisory program since this goal coincides with national Sea Grant objectives. The advisory service need not be limited to Sea Grant programs, however.

3. Yearly Workshops on the Coastal Zone

A strong suggestion from the workshop participants was the continuation of workshops as a means of encouraging and promoting both scientist-to-scientist exchange of information, and also scientist-user communication. This yearly format would provide a timely communication vehicle, since scientific articles are published with a considerable lag following completion of the studies (a delay of a year, or even two, is not unusual). These meetings would include active coastal zone scientific researchers, as well as management and policy people to some degree. Since private industry (such as consulting firms) play a dominant role in applying scientific results to practical problems, they should be included in the workshops. The consultants would be able to state their knowledge gaps and perhaps encourage scientific research in those areas.

4. Establishment of a Massachusetts coastal zone data bank

CZM personnel are occasionally unaware of scientific research pertinent to a particular problem. The suggestion was made that a reprint bank containing articles and reports dealing with various coastal topics be established. This could be maintained by CZM employees and the scientific community together. Response to this suggestion varied. The majority conceded that such a library would be useful, but would be of limited access to the general scientific and lay community if available at only a single location. CZM has evidently begun a compilation of literature on the Massachusetts coastal zone, and may establish such a library in the future.

5. Encourage scientists to become more aware of community problems

B. Deficiencies in Our Knowledge of the Massachusetts Coastal Zone

In an effort to candidly assess the shortcomings in our knowledge of the Massachusetts coastal zone, and to encourage study of particular areas of nearshore processes, the following list was developed from comments of the workshop participants. The list is not exhaustive, and clearly reflects the prejudices of the workshop participants. One area not emphasized is the inter-disciplinary study of coastal zone problems, including, for instance, chemistry and biology. These interactions and multidisciplinary studies are necessary, but were not discussed in detail since they were peripheral to the main thrust of this workshop.

The ideas for this outline were derived primarily from the workshop. The interpretation of the ideas belong to the author, so they may not precisely reflect the spirit of the workshop suggestion. The organization of the outline was arbitrary; some topics would fit equally well in any of several sections.

1. Coastal Zone Data Inventory

One of the major deficiencies in our knowledge of the Massachusetts Coastal zone is the lack of a catalogue of work previously performed within it. This situation can be easily remedied and would be an important input for many planning and research efforts; it would also prevent needless duplication and encourage more scientifically-based management decisions. The major areas of nearshore research suggested by the participants for cataloguing include:

(a) Beach Profile Inventory - A catalogue of all beach profiles, both onshore and offshore, could improve coastal planning efforts by providing historical shoreline change information. Such a catalogue would probably show that limited profiles (generally onshore only) exist for large stretches of the Massachusetts coastal zone.

(b) Inventory of coastal and offshore currents - Many investigators have collected current measurements over various time periods at many different locations. If these were catalogued in one place, the coastal planner (and scientist as well) would have a better picture of nearshore circulation patterns. This information is valuable for many tasks: research, oil pollution studies, dumpsite evaluation, general pollutant dispersal, and biological exchanges.

(c) Inventory of Wind Data - The wind field provides information on different types of forces in the nearshore - currents and waves, for instance. A catalogue of this information could be combined with current data, to model the coastal wind-driven surface flows. This information is valuable for pollutant dispersal studies, both in the ocean and atmosphere, and oceanic mixing studies.

(d) Beach type inventory - An inventory of beach type (according to pertinent physical characteristics) along the Massachusetts coast would be valuable for research and planning purposes. It would help evaluate erosion potential along the coast. Pertinent beach characteristics could include: beach slope, sediment size, seasonal beach changes, wave and wind exposure, longshore transport barriers, sediment sources and sinks, and anthropogenic influences.

(e) Beach Erosion/Cliff Erosion Inventory - An inventory of beach and cliff erosion could be performed using previous investigations of the coast. Certain historical studies are available as well as raw data, which could be catalogued on a set of maps for rapid access and interpretation. This would serve to expose those sections of coast which have not been studied in great detail, as well as insure that coastal planning decisions are made with all available data. The maps could be updated periodically, perhaps during a coastal zone workshop. Much discussion on such a map took place during the workshop, with participants suggesting that such an erosion inventory be performed as part of this Coastal Zone Workshop series. Plans for such a project are being evaluated for the next workshop, if funding can be found.

2. Wave Climate and Wave Shoaling

Since one of the principal forcing functions for nearshore particle transport is the wave field, one needs to know wave properties with a significant degree of accuracy. In general, our knowledge of statistics of the wave field and the hydrodynamics of wave shoaling is inadequate to predict details of sediment transport. Specific areas of suggested research in wave problems include:

(a) Wave Climate - The most frequently mentioned deficiency in coastal research was the lack of a statistical wave climate for the Massachusetts coastline. No accurate field statistics for wave frequency and directional distribution over a significant time period exist for most areas bordering Massachusetts. Hindcasts and site specific non-directional wave estimates exist on a scattered basis, but are not sufficient for sediment transport, coastal erosion, or storm surge applications. Different techniques suggested for wave measurement include pressure sensor, aerial photographs, mapping of dominant wavetrains from airplanes, micro-seism analysis, surf observations, satellite and ship observations. These techniques are adequate for specific applications, but do not obviate the need for wave frequency-direction statistics required for many coastal studies. A frequency-directional distribution is required if the wave information is to be used elsewhere, since one can derive deep water estimates from this information. Without direction, deep water information cannot be obtained from a shallow water measurement.

A wave climate for deep water should be measured, either directly or by refracting out some shallow water measurements. Then site specific wave parameters can be derived from these deep water measurements by refracting deep water waves into a particular coastal location.

(b) Wave shoaling and wave scattering - The transformation of wave trains from deep water to breaking nearshore has yet to be completely solved. Linear wave theory is generally assumed for waves in shallow water, but fails to take into account non-linearities and some aspects of wave scattering. Much more research, both theoretical and field-oriented, is required before the scientist can describe wave shoaling characteristics, and derive, for example, breaker heights and depths from deep water wave statistics. The internal dissipation of waves is poorly understood as well, so reduction of wave energy flux with distance needs more clarification.

(c) Bottom friction - As waves propagate over the shelf, they are dissipated through bottom friction. The magnitude of the bottom friction is poorly known, and indeed may be a critical factor in limiting the size of design waves in the coastal zone. Since the energy extracted from the waves and currents through bottom friction is partly expended by moving sediment, knowledge of bottom friction is necessary for analyzing sediment transport as well.

3. Sediment Transport

This subject is extremely broad and must rely on results from many diverse but related fields. This section is a repository for many related topics, and therefore is not clearly defined. Sediment transport causes many coastal and marine problems, and is a critical subject for many planning and management decisions. Some of the major topics to be studied include:

(a) Longshore sediment tranport theory - Since the mid-1940's longshore transport theory has relied on an empirical, semi-quantitative theoretical framework. As was discussed by some of the workshop presentations, this framework is inadequate for high-quality predictions of longshore sand transport. More specific lines of future research include accurate measurement of longshore transport rates and the driving forces, theoretical improvement of longshore current models, and improved techniques for measuring longshore sediment transport rates in the field.

(b) Swash Zone Motions - This topic is related to the previous one in that it includes longshore currents. In addition, however, it includes the measurement and analysis of energy exchange between different frequency components. In particular, how is the energy spectrum in deep water, which is dominated by wave frequencies, transformed into a swash spectrum which is sometimes dominated by low frequency (order of 100 seconds) motions? The study of the swash currents should clarify many aspects of sediment transport on the beach foreshore, as well as answering questions about nonlinearities in wave breaking.

(c) Bedload and Suspended Load Computations - Sediment transport is conveniently divided into bedload and suspended load, where bedload is that sediment transported in a regime where grain-to-grain interactions are at least as important as fluid-grain interactions. Practically, it is difficult to separate the two classes of motion, although it is necessary to do so in order to understand the physics underlying that motion. The first step is to define through theory and experiments an unambiguous and universal criterion for these two types of motion, while at the same time measuring the magnitude of these two components to quantify nearshore sediment transport. Much work remains on the measurement and theoretical framework themselves, and then these transport rates must be related to the flow kinematics. This is difficult since sediment transport, which in large part results from the flow, itself influences and alters the flow. Models are required which account for this feedback between sediment transport and fluid flow.

(d) Size and shape sorting - A specific aspect of the previous section is the effect of grain size, shape and sorting on sediment transport. This topic was addressed in a couple of the presentations, but much work remains to quantify these effects.

(e) Role of the offshore region in the sediment budget - It is not known whether the offshore regions serve as a source or sink of sediment to the nearshore. This problem can be resolved by a number of techniques (e.g. profiling, mineralogic studies), but any study must be done with great care and precision. This question has significant impact on the future of many coastal regions. Better sediment transport models are critically needed for this region, including the effects of waves, bottom slopes and currents.

(f) Tidal Inlet Problems - There is a variety of tidal inlet problems which need to be addressed. Although tidal inlets have been studied quite extensively, much more work is required before the crucial problems are solved. Examples are: is the tidal inlet a source or sink of nearshore sediment; how does longshore transport bypass tidal inlets; what are the hydrodynamic factors controlling tidal inlet stability?

4. Mass Sediment Movement

The previous sections have emphasized primarily fine scale details of sediment and fluid motions. Another important consideration is the large scale movement of sediment. Two examples are given here:

(a) Cliff erosion - Slope failures along coastal regions provide sediment to the nearshore sand budgets. Unfortunately, these slope failures also destroy private and public property. The factors responsible for slope failures need to be quantified, and critical areas of failure mapped.

(b) Submarine Landslides - Subaqueous slope failures are a major consideration in offshore sedimentation. They are responsible, for instance, for removing sediment from the nearshore through submarine canyons. They can also cause structural failures offshore, an example being the rupturing of a drill-string and subsequent oil spill due to failure of sediments near a drilling operation. The mechanisms and frequency of such occurrences must be documented before increased drilling and mining operations take place off our coastline.

5. Measurement Techniques

Instrumentation currently available is not adequate for making all the measurements required to resolve all our nearshore problems. The instruments now available are not adequately understood; it is not clear what flow parameters some of these instruments are recording. Testing is required to state with confidence that the instrument is recording unaltered flow fields. Clearly we need to develop our measurement capability with new ideas and improved technology, as well as judicious selection and design of experimental equipment. New approaches for monitoring the coastal zone are required: the capabilities of remote sensing must be evaluated and exploited, since it provides a synoptic overview not available with other techniques. Coastal vessels must be available to serve as platforms for coastal work; the appropriate vessels now are difficult to get and often too expensive for their capabilities. A carefully designed coastal vessel, although perhaps as expensive, would expand the effectiveness of coastal research.

6. Man's impact on the Coastal Zone

Much is known about man's impact on the coastal zone. Less is known about how to reduce this impact while still allowing full use of the coastal zone. These topics must be addressed in the future, both by planners and managers who must administer and preserve the coastal zone, and by scientists who can provide scientific results with which to make more informed decisions. A comprehensive list of topics for future study in this regards would be endless, but a few specific suggestions were mentioned at the workshop.

(a) Influence of structures on the coastal zone - Much work has been done on this problem, but much more remains. The effects of structures on nearshore sediment transport, nearshore circulation, and on shelf transport (e.g. through scour) need to be more comprehensively analyzed.

(b) The effects of sand and gravel mining - Many areas are turning to offshore sand and gravel mining for construction materials and beach nourishment. The effect of this mining is largely unknown, and depends in part on the results of section (3-e). The influence of mining on sediment movement and on wave scattering needs to be evaluated to avoid long-term effects on the coastline.

(c) Dredge Spoils - Spoils from nearshore dredging projects are sometimes dumped in deeper water for lack of other suitable repositories. This dredge spoil may diffuse under the influence of waves and currents, changing biological habitats and sediment characteristics. If the dredge spoil has heavy metal concentrations or other chemical contaminants, it could have severe impact on the biology and nearby coastal communities.

(d) Oil Spills - The effects of currents, wind and waves on the dispersal of oil slicks needs further study. The definition of seasonal wind, wave and current patterns would be a necessary input for this type of study. With the advent of increased oil production off the eastern continental margin, the probability of such an oil spill increases and this problem becomes more acute.

(e) Offshore dumping of contaminants - Industrial wastes, and perhaps in the future nuclear wastes, are dumped in deep water with the hope that the material is lost to the coastal zone forever. Recent studies have shown that such deep-water dumping products may persist near the surface for long periods of time, perhaps encroaching on the coastal zone once more. Large scale circulation patterns must be better defined off the east coast to assess the dangers of such dumping. In addition, more studies on oceanic mixing and transport are needed to define a residence time for these materials near the surface waters where they may be rapidly advected towards the coast.

(f) Tidal Inlets - What are the effects of man's activities on tidal inlet processes? Are short-term solutions consistent with long-term cycles? A good example of the tidal inlet problem is Chatham Inlet on Cape Cod, Massachusetts, where stop-gap (but expensive) solutions may be extremely short-lived.

(g) Public versus private beaches - The large stretches of private beach along the Massachusetts coast make it difficult to implement a coherent, inclusive coastal protection plan. the far-reaching implications of private beach ownership should be categorized and assessed, so we can intelligently state our limitations in coastal protection capability.

(h) Repair of storm damage - Repairs designed to retain the status quo of a coastal area after storm damage can accelerate future erosion. Man's response to storm damage needs to be analyzed to eliminate counter-productive post-storm activities (i.e. use of dune blow-outs on barrier beaches for vehicle access).

IV. ACKNOWLEDGEMENTS

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V. APPENDICES

Workshop Participants - Appendix 1

Workshop Agenda - Appendix 2

Workshop Presentations - Appendix 3

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APPENDIX 2

WORKSHOP ON COASTAL ZONE RESEARCH

TENTATIVE AGENDA

Clark Laboratory - Fifth Floor Conference Room

Monday, 27 November 1978

0900	*Registration - Coffee, Tea, Donuts*	
0930 *1000*	D.G. Aubrey, D. Ross, D. Spencer *Woods Hole*	*Introduction and Preliminary Remarks*
1000 *1020*	G. Giese *Provincetown Center for Coastal Studies*	*Keynote Speaker* *Historical overview of Massachusetts coastal zone studies*
1020 *1200*	*Beginning of informal talks*	
	K.O. Emery *Woods Hole*	*Sea levels and deformation of the Geoid*
	W.D. Grant *Woods Hole*	*Wave-current interactions in the coastal zone*
	S. Williams *Woods Hole*	*Instrumentation problems in the coastal zone*
	J.R. Allen *Northeastern University*	*Spatial and temporal variations in longshore sediment transport - geologic and management implications*
	R. Beardsley *Woods Hole*	*Upwelling on Nantucket Shoals*
1200	*Luncheon -* Carriage House	
1300 *1500*	*Continuation of Informal Talks*	
	B. Brenninkmeyer *Boston College*	*Sediment movement at selected sites in Massachusetts*
	J. Southard *M.I.T.*	*Fine sediment erodibility in inner-shelf environments*
*	J.R. Jones *Boston State College*	*Coastal geomorphology of Boston Harbor islands*
	M. Fitzgerald *W.H.O.I./M.I.T.*	*Source and Fate of fine-grained sediments in Boston Harbor*
	R. Spayne *Boston State College*	*Undergraduate coastal projects at Boston State College*
	W. Fox *Williams College*	*Surf zone - tidal inlet interactions*

APPENDIX 2

Monday, 27 November 1978

Agenda (continued)

1500 *1530*	O. Madsen......................... *M.I.T.*	*Keynote Speaker* *Surf zone processes - what we do and don't know, with special reference to longshore sediment transport*
1530 *1700*	*Continuation of Informal Talks*	
	G. Giese......................... *Provincetown Center for Coastal Studies*	*Causes of shoreline retreat along the North Atlantic coast of the United States*
	A. Gutman......................... *M.I.T.*	*The perched beach low cost shoreline protection technique, and Nantucket historical and current shoreline survey*
*	D. Fitzgerald......................... *Boston University*	*Present coastal investigations with some preliminary conclusions*
*	B. Cameron......................... *Boston University*	*Physical effects of quartzose algal mats on sedimentation and dune development - Plum Island Spit, Massachusetts*
	J. Fisher......................... *University of Rhode Island*	*Photogrammetric survey of long-term shoreline changes: Nantucket Island and Boston Harbor Islands*
1700 *1830*	*Unwind with beer and wine* - Clark 507	
1830	*Buffet Dinner* - Clark 507	

* Unable to attend

APPENDIX 2

WORKSHOP ON COASTAL ZONE RESEARCH

TENTATIVE AGENDA

Clark Laboratory - Fifth Floor Conference Room

Tuesday, 28 November 1978

0800	*Coffee, Tea, Donuts*	
0830 – 0900	D.G. Aubrey, *Woods Hole*	*Recap of previous day's lectures - discussion*
0900 – 1000	*Conclusion of informal talks*	
	L. Smith, *Coastal Zone Management*	*The role of coastal geology in the Massachusetts Coastal Zone Management Program*
	M. Wild, *The Martha's Vineyard Commission*	*Impact of shoreline retreat on Vineyard's south shore*
	S. Leatherman, *U.S. National Parks Service*	*The effects of storm processes and off-road vehicles on Nauset Spit, Cape Cod National Seashore*
	* P. Godfrey, *U Mass & Nat'l Park Service*	*Ecology of barrier beaches and islands - role of vegetation as geomorphic agents*
1000 – 1200	*Discussion session*	*1) Needs of State and local agencies in coastal zone problems* *2) How we can interact with them?* *3) Deficiencies in our knowledge of coastal zones, Massachusetts in particular*
1200 – 1300	*Luncheon* - Carriage House	
1300 – 1600	*Discussion* - Carriage House *(approximately)*	

1) What can we do to remove the deficiencies in our knowledge of coastal zones?

2) What approach shall we use?

a) cooperative, planned studies, or
b) individual investigations

3) Are there any funding sources or programs being ignored?

4) What form, if any, is the "Proceedings" going to take?

5) Formulate workshop "Proceedings"

6) Feedback on workshop - Do we learn from these?

* unable to attend

APPENDIX 3

WORKSHOP PRESENTATIONS

SPATIAL AND TEMPORAL VARIATIONS IN LONGSHORE SEDIMENT TRANSPORT: GEOMORPHIC AND MANAGEMENT IMPLICATIONS

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Rates of longshore sediment transport are a function of the transportable sediment supply, usually sand, and the shore-parallel stress of oblique waves, rip cells, and tidal currents. Using a continuity approach, lateral variations in the transport rate result in beach erosion or accretion. These response rates are thus directly related to the process rates, and one should evaluate the transport rates when studying the problems of shore erosion and inlet shoaling. Because beaches are utilized themselves and act as dynamic buffers for inland areas, coastal zone managers also need the information to fit the most appropriate land use to the land parcel, or most efficiently protect existing land uses where rezoning is impractical.

The concepts of a littoral drift cell of transport from a source to a sink are effective in studying sediment budgets. The cells have a wide variety of rates and geomorphic expressions that relate the supply of sediment to energy. Coastal geomorphology expresses a volumetric control on the availability of sediment being great for backing uplands, sediment laden rivers, and wide, shallow nearshores. Lithology is important as a control on the rate of supply, e.g. high for sandy coasts. The local shoreline lineation can be thought of as a measure of the efficiency of longshore transport; where very crenulate, essentially zero transport is found. Cove beaches are geomorphically sheltered such that only on/offshore movement occurs and the sediment supply is locally limited to limb destruction and backing cliff materials (including a mantle of till in Massachussetts). North of Boston, cobble beaches predominate in coves, and some work at Nahant has shown that they are very dynamic when high energy waves are towards the beach. These beaches seem to be in an equilibrium that includes normal storms and shortly re-establish their previous form, although with a series of relict berms. Storms with low recurrence probabilities, however, drastically change the beach because of the offshore losses being irrecoverable by post-storm waves. The February 1978 storm displacement of a beach at Nahant was such that seven months later the equilibrium form was re-established nearly ten meters inland along with a total cliff erosion (including the subsequent mass wasting of nearly four meters of till). Longshore inputs would minimize this.

Wave refraction is often employed in coastal studies because it correlates the local geomorphology with the wave processes. The technique also reveals shore-parallel changes in the transportation rates because of offshore topography and changes in shoreline orientation.

The actions of man are also important because watershed controls often decrease the fluvial sediment supply to coasts, armoring of the shore leads to a zero sediment supply condition, and breakwaters, groins, jetties, and dredging all change the local transport rate.

Temporal differences in longshore transport rates are largely attributable to energy variations within the wave climate. While the west coast is seasonally simplistic, the Northeast responds in a cyclic fashion to the high-frequency passages of extra-tropical cyclones, where effective winds come only out of the easterly quadrant. Whereas much of the documented increase in storm damage can be attributed to greater intensities of occupance, the actions of man, and a rise in sea level, our work has suggested an increase in the net violence of storms, as well. Using weather data for New York City, a storm index (the frequency of days with easterly winds times the mean daily wind velocity squared) indicates that the 1970's are twice as stormy as the 1950's. In general, the increase is due to greater storm durations, although the mean wind velocities increase also. The same trend has been identified by others in the Mid-Atlantic states for an earlier period. The higher wave energies will increase the annual transport rate, if there exists a sufficient sediment supply. The increase in demand is usually supplied by the beach, itself, hence erosion.

Most of the work to date has focused on the longshore transport rate being a function of the longshore energy flux factor, $I_l = k\ P_l$ where $P_l = E\ Cn \sin\gamma \cos\gamma$. Komar's tracer study indicated that $k=0.77$ and our trap studies have, with a greater data scatter, substantiated the value when the bed load is assumed to advect at one-tenth the suspended load velocity. We have also tested our data from traps against the energetics model (that can incorporate the effects of such non-wave driven currents as tidal and surface winds) where the immersed weight transport rate $I_l = k\ E\ Cn \cos\gamma\ v/u_m$. Again we agree with Komar in that $k=0.28$ as a best linear fit in the power function, but there is a great deal of data scatter.

Erosion will occur when there is less sediment input than sediment output along the lateral beach direction. Updrift controls on the sediment budget include dams, headlands, inlets, submarine canyons, and erosion control structures leading to a deficiency of sediment relative to the available transportational energy. Erosion also results from a disequilibrium caused by storm waves. Ideally, the geologist wants to know where, when, and how much beach change may occur. We have been working on a computer simulation model that refracts waves to the breakpoint, calculates sediment transport, and resolves the horizontal amount of beach change. While it relies on some empirical constraints and is theoretically inadequate, in a crude fashion it works. Certainly this type of modelling offers great savings in time and money to the coastal planner in that, through simulation, many coastal problems and various solution strategies may be evaluated.

THE STATISTICAL PREDICTION OF BEACH PROFILE CHANGES

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One of the major deficiencies in our knowledge of coastal processes is an inability to accurately predict the direction or quantity of nearshore sediment transport. Velocity fields in the nearshore are quite complex, with time scales ranging from high-frequency turbulent fluctuations to low-frequency seasonal variability. All of these time scales must be understood before nearshore sediment transport can be predicted analytically. For simplicity, nearshore sediment transport is usually divided into two components - longshore transport versus on/offshore transport. Research is underway on each of these modes to clarify the mechanisms and patterns of nearshore sand redistribution.

Since nearshore flow-fileds are so complex, analytical modeling is sometimes replaced by statistical modeling. This summary considers the statistical prediction of on/offshore sediment transport, using beach profiles as indicators of net sand movement. The use of beach profiles in predicting on/offshore motion relies on the assumption that net chnages are not due to local divergence in longshore transport. If this assumption is fulfilled, profile changes will represent net on/offshore sand movement. Statistical models do not clarify (or necessarily even address) the physics of sediment transport, but they can be used judiciously to test ideas of beach response to changing forcing conditions.

Statistical modeling has several drawbacks. The results are at best as good as the data used to formulate the model. Since the models rely heavily on past statistics of the covariance between beach profile changes and the forcing functions, long time series are required to increase statistical reliability. In addition, these techniques require simplifying (often subjective) assumptions much the same as do analytical techniques. In the case of profile prediction, the beach changes are assumed to be two-dimensional, thereby ignoring the effects of longshore transport and longshore currents. The best statistical models combine well-founded physical insight and statistical techniques with a high-quality data set to verify the models. The following discussion assumes such a high-quality data set exists.

Statistical Techniques

The three statistical techniques discussed here have been used previously to predict beach profile changes, and therefore on/offshore sediment transport. Alternative statistical techniques could be used instead, but they are not discussed since they have not been used to predict profile changes.

The first technique is empirical eigenfunction analysis, also known as factor analysis, principal component analysis, or empirical orthogonal function analysis. This analytical scheme optimally reduces a data set into a series of orthonormal functions, ranked according to the amount of variance they describe. This technique is the most efficient representation of the data in the sense that the first n empirical functions describe as much or more of the variance of the data than the first n functions of any other orthogonal set. This technique is useful because it is both objective and concise.

Beach profile data can be analyzed using this method. Winant, Inman and Nordstrom (1975), Winant and Aubrey (1976) and Aubrey (1978) describe the method in greater detail and present results demonstrating their utility. They show that the eigenfunctions of the beach profile data have physically meaningful analogues and indeed represent major cycles in beach variability. The first function represents an average beach profile, with little time variability. The second eigenfunction is a seasonal function representing seasonal beach changes. Higher order eigenfunctions represent higher frequency beach changes, and are physically less meaningful than the first three or four functions. Empirical eigenfunction decomposition of beach profile data efficiently and meaningfully parameterizes beach profile changes.

The second technique is Linear Statistical Prediction, used to predict beach profile changes based on some parameterization of the forcing function (waves and tides, for instance). Aubrey (1978) has demonstrated that seasonal (and to a lesser extent, weekly) beach changes are predictable using weekly averages of wave height and wave energy. Daily profile changes are also predictable using forcing functions such as wave energy, radiation stress, wave steepness, and energy flux, but the statistics governing this predictability have not been evaluated because of a limited data set. The prediction was tested for a beach in southern California, and must be tested elsewhere before it can be used with confidence.

An alternative prediction technique is Canonical Correlations, developed by Hoteling (1936). This technique is similar to the Linear Statistical Predictor, but is formulated in a slightly different manner. The Canonical Correlation method maximizes the correlation between two sets of variables, producing new variables which are optimally correlated and consisting of linear combinations of the original variables. Cooley and Lohnes (1971) discuss this technique and its application in more detail. The two prediction techniques give results which are similar, and need to be tested on other data sets to determine which predictor is better. The Canonical Correlation results are somewhat more difficult to interpret than the Linear Predictor results, so the latter may be more desirable from the standpoint of interpretation.

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SEDIMENT MOVEMENT AT SELECTED SITES IN MASSACHUSETTS

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During the past several years, a number of studies have been conducted to determine the dynamics of sediment movement in various localities of the coast of Massachusetts.

Nauset Light Beach

The outer arm of Cape Cod between Nauset Light and the Nauset Light Coast Guard Station has suffered severe erosion. To quantify the rate of erosion, a series of survey stations established by Marindin (1898), Zeigler and his colleagues (1964) and Chamberlain and Martin (1974) were reoccupied during 1978. The erosion rate for the entire 1.5 km of surveyed coast averaged 0.62 m/yr. The cliff face just south of Nauset Light has retreated 110 meters since 1898. Coastal retreat, at that point, averaged 0.94 m/yr between 1898 and 1956, 1.04 m/yr between 1956 and 1973 and 5.49 m/yr between 1973 and 1978. Most of this erosion presumably took place during the Blizzard of '78. Over the past five years $132 m^3/m$ has been added to the beach to be transported by waves and currents.

During a storm in October 1975, the sediment concentration within the water in the surf zone at Nauset Light Beach was measured by almometers (Brenninkmeyer, 1976). Most of the sediment movement within the surf resulting from breakers estimated to have been 3 m high, is intermittent. The movement occurs not at the main sea period, but at periodicities greater than 15 seconds. Approximately 30% of the spectral power of the sediment movement is in periods greater than two minutes. This indicated the importance of the bore-backwash interaction and shelf waves, surf beat and edge waves in moving sediment. The average concentration at any given second was 2.4 g/l in the onshore/offshore direction and 1.5 g/l in the longshore direction (Leonard and Brenninkmeyer, in press). In that storm, 86 m^3/m/day moved normal to the beach, while 55 m^3/m/day was in motion along the beach. Most of this sediment must have been recycled and moved first in one direction alongshore and then in the other direction, for this figure is 1000 times greater than the net littoral drift in this area (Zeigler and others, 1964).

Measurement of the water velocity within each incoming bore by an array of bidirectional current meters showed that the water pulsates frequently back and forth (Brenninkmeyer, 1978). This is true for all three orthogonal axes which act in unison. As the bore crest passes a point, there are strong onshore, down and one longshore components. This is immediately followed by an offshore, upward and the other longshore direction pulse. This couplet repeats itself at least twice and up to eight times per wave. The strongest pulses occur almost at the same time as the bore crest passes overhead. The offshore pulses generally increase in strength up to the arrival of the next bore crest. The magnitude of the envelope of the fluctuations of the vertical and longshore components increase and wane.

This frequent movement of the water back and forth is reflected in the sediment movement. Sand samples collected with five bidirectional traps of 1 cm^2 opening spaced at 7 cm intervals above the bottom in the surf at Nauset Light Beach vary over a large range from 0.01 to 34.7 grams per wave (James and Brenninkmeyer, 1977). Within each wave, roughly the same order of magnitude is transported onshore as offshore. The onshore direction is favored during the flood tide. Similarly, within each wave roughly the same quantity of sediment is transported in both longshore directions. Only a slight increase is noted in the predominant longshore direction (Brenninkmeyer, James and Wood, 1977).

Nauset Inlet

A little further to the south at Nauset Inlet, the coastline has eroded 0.8 km since 1605 (Wright, 1977). During August 1975, a washover occurred on the north spit at the inlet creating a new channel. On a bimonthly basis, this new channel and subsequent changes were surveyed as 57 sediment samples were collected. Five geomorphically distinct provinces were readily discernable at the inlet: upper and lower beach face at the open ocean, intertidal found on the backshore, channel and dune. Nonlinear discriminant analysis correctly classified 91% of the samples in August. This number fell to 88% in October, 54% in February, and 48% in May.

It was not till May 1976, that the flood tidal delta characteristics of flood ramp, flood tidal channel and ebb shield became discernable on the breached spit and longitudinal sand bar which has formed in the channel during the winter months. Reclassification of these two areas as a tidal delta improved the classification of the February and May samples to 74 and 73%, respectively (Wright and Brenninkmeyer, 1978). From this, it appears that sedimentological differentiation of a flood tidal delta appears before its geomorphic expression.

Essex Estuary

The concept of using grain sizes to delineate geomorphic environments was also used to determine sand wave development in the Essex flood tidal delta. The Essex estuary is located 40 km north of Boston. In the flood channels of the flood tidal delta, 15 cm high sand waves 10 m apart migrate at a rate ranging from 1-40 cm/tidal cycle varying with the neap to spring tides, respectively. In order to measure the rate of sand wave formation, a 20 x 8 meter area was leveled in September, 1977. Weekly surveys of the elevation changes were made. In this environment, with tidal currents up to 55 cm/sec, sand waves develop completely in 60 days. In that time, 37.8 hours of velocities greater than 47 cm/sec were attained.

During the survey, on a biweekly basis 100 sediment samples were collected. Before the leveling, by a nonlinear discriminant analysis, 95% of the sediment samples were correctly classified into the three sedimentary environments of sand waves: crest, stoss and trough. Using these three and the leveled sand characteristics, four control groups were obtained. Seven days after leveling, 44% of the samples taken from the leveled area fell within the sand wave categories. This improved to 69% after three weeks and 83% after seven weeks (Holden, 1978).

Mann Hill Beach

Mann Hill Beach in Scituate is a shingle bay mouth bar. Net landward movement of the pebbles during normal sea conditions is small. During storms, pebbles of all shapes are brought in by waves. During the Blizzard of '78, 95.9 m^3/m was eroded from the bar lowering the top of the beach almost 3 meters. Of this quantity, 25% was redeposited in a 1m thick, 35 m wide overwash deposit. Discs being lighter than a sphere of the same mean diameter and having a lower settling velocity than any other shaped pebble are thrown up higher on the beach. These discs make up 70-80% of the back beach deposit. After the storm, shape sorting starts. In a traction carpet, spherical and rod-shaped particles move faster than discs, for discs have a lower pivotability (Kuenen, 1964). Therefore, spheres and rods will be transported further seaward by the backwash. Almost always there is a fringe of spherical and rod-shaped shingle seaward of the gravel, (see Table 1). While the discs lag behind, they are not stationary. Percolation of the backwash produces an imbrication of the pebbles such that they dip seaward. By means of a caterpillar-type action, these discs are slowly moved seaward. This movement is irregular, resulting in a wide range of dip values (Brenninkmeyer, 1976).

TABLE 1

%	MLW	10 Meter Intervals			Berm
Disc	42	52	59	60	75
Blade	4	10	12	36	29
Roller	16	16	14	2	5
Equant	38	22	14	2	0

Martha's Vineyard

Erosion rates at Mann Hill Beach are small compared to the 2.3 m/yr rates at Katama Beach on the south shore of Chappaquiddick Island on Martha's Vineyard. The eastern point- Wasque Point - has eroded 10 m/yr from 1938-1969 (Kaye, 1973). Historically, the most important event affecting the shoreline changes in this area is the breaching of Katama Beach. The inlet forms every 15-25 years at the western end of Katama Bay. The inlet then migrates eastward till it is closed by longshore transport at Wasque Point. Wave refraction studies show that waves coming from the southwest, south, and southeast focus their energy on the western edge of Katama Bay (Wood and Wall, 1978). This accounts for the narrow (less than 100 m) beach in this area and the frequent overwashing. However, breaching occurs during nor'easters and eyewitness accounts (Odgen, 1974) describe the beach as being breached from the bay side. This breaching must be similar to piping failure in a dam. The tide in the bay lags approximately 2 1/2 hours behind the ocean. This, together with the wind set-up, provides a pressure gradient from the bay to the ocean. In addition, water from rain saturates the beach and increases the pore pressure. Therefore, the effective stress and the shear strength of the sand decrease drastically. Storm driven water within the bay exerts a seepage pressure on the sand causing subsurface erosion and inlet formation (Wood, Wall and Brenninkmeyer, in press).

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PHYSICAL EFFECTS OF QUARTZOSE ALGAL MATS AND DUNE DEVELOPMENT - PLUM ISLAND SPIT, MASSACHUSETTS

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Recent discoveries of quartzose algal mats in temperate coastal marine environments dispel the widely held concepts that marine stromatolites (1) occur in either arid or tropical to subtropical environments and (2) are restricted to carbonate sediments.

At Plum Island, Massachusetts, the most extensively developed algal mats occur along the high intertidal to supratidal margins of a hypersaline pond between beach ridges on a spit growing at the southern end of the island. These sediments consist of laminated quartz silt and fine-grained sand bound by mucous-secreting, filamentous blue-green algae. Mat-forming algae flourish in this environment where normal marine algae, metazoans, and higher plants are restricted.

The upper 1 mm of the mat is dark green due to filaments of Lyngbya, Microcoleous, and possibly other (smaller) filamentous cyanophytes (blue-green algae). Coccoid cyanophytes (including Entophysalis?), Euglena, nematode worms, and diatoms are also present. Below this upper layer, there is a thinner, pinkish layer containing purple sulfur bacteria. Underlying the pinkish layer, there usually is black sand 1-7 cm thick indicating anaerobic conditions. It contains older mats whose lamina can be recognized from both layers of decaying organic matter and alternating layers of water-laid and wind-blown silts that are probably storm derived. Gelatinous material aiding filament-binding of sediment extends 1-7 mm below the upper surface.

Algal mat growth affects physical sedimentation in part of the inter-dune area of the Plum Island spit by stabilizing the sand in several ways:

(1) The algae bind silt and sand with mucous and filaments to form a cohesive surface that inhibits erosion.
(2) After storms which bury the mats under overwash and/or aeolian sediments the algae recolonize and bind the new surface. This aids in the upward growth of the spit.

(3) Storms and high tides that partially float and even overturn and roll the mats and/or dessicated mat polygons tend to form mounds that are more easily colonized by root-bearing vascular plants which further stabilize the sand.

(4) The mixed algal mat-vascular plant mounds trap windblown, loose sand in between the vascular plants' stems and leaves to form incipient dunes that gradually coalesce to develop higher topography.

COPPER CONTAMINATED SEDIMENTS IN NEW BEDFORD HARBOR

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In 1975, Woods Hole/Sea Grant funded a two year study of the study of fine sediment movement and distribution in the enclosed harbor of New Bedford, Massachusetts. As part of this study, it was decided to determine the extent of heavy metal contamination in the bottom sediments of the harbor. The findings of this study have been published in two Woods Hole technical reports (Summerhayes, et al., 1977; Ellis, et al., 1977) and one journal article (Stoffers, et al., 1977).

The bottom topography of the study area is characterized by N.W. - S.E. trending valleys and ridges, which are a product of local bedrock geology and the glacial history of the region. Superimposed on the natural topography are two significant man-made features: the dredged channel and the New Bedford Hurricane Barrier. Bottom sediment distribution is a function of this topography (Fig. 14 from Summerhayes, et al., 1977). The amount of organic matter present in the bottom sediments is a function of both sediment type and location (Figs. 20 and 21 from Summerhayes, et al., 1977).

Published and unpublished data from the New England Aquarium (1973), the New England Division, U.S. Army Corps of Engineers and the Massachusetts Division of Water Pollution Control (1971,1975) were used to supplement our own data. Harbor sediments were known to be highly reducing, with redox potentials ranging from -2.48 to -4.88 mv, and to be enriched in a number of heavy metals. When compared to sediments from central Buzzards Bay, enrichment reaches factors of X 500 for Cu, X 100 for Cr, X 40 for Cd, X 30 for Zn, X 25 for Ni, X 20 for Pb, X 13 for Hg and X 7 for As. In one area of the inner harbor, Cu + Cr + Zn constitute 1.17 percent of the dry weight of the sediment. Metals are only some of the high level pollutants which can be found in the sediments and waters of New Bedford Harbor.

The levels of Cu in the sediments of New Bedford Harbor are of major interest since they are the second highest values which have thus far been reported for any similar location in the world. Copper levels in bulk, surface samples from the inner harbor range from 520 to 2500 ppm, the mean being 1063 ppm. The amount of Cu in the sediments decreases exponentially away from the inner harbor (Fig. 28, Summerhayes, et al., 1977). Several areas of elevated values are of special interest, however. Elevated Cu values near the New Bedford spoil area probably represent effects from previous dredging and dumping operations. At the present time, there appear to be two major sources of Cu in the study area: Revere Copper and Brass, located along the western shore of the upper harbor, and the sewage treatment plant at Clarks Point. Records available from E.P.A. and an unpublished engineering study on the New Bedford sewer system indicate that each source contributes approximately the same amount (30 kg) of Cu to the environment each day. Copper concentrations near the Revere Copper and Brass plant run as high as 8500 ppm in the clay fraction, while the maximum concentration in the clay fraction of bottom sediments near the sewer outfall was found to be 530 ppm. Our data indicate that much of the Cu present in the inner harbor may be in particulate form. We suspect that most if not all of the Cu liberated at the sewer outfall is in dissolved forms which quickly complex with the organic matter present in the marine environment.

At the present time, there are still a number of interesting questions awaiting answers. Copper is known to be a common product of most municipal sewer systems. Given the distribution of Cu that is known to exist, it would be of value from an environmental management standpoint to trace the depositional pattern of outfall Cu. Some work is presently underway in this direction. Another critical need is for current data inside the hurricane barrier and for additional data outside the barrier and especially around the sewer outfall.

One of the disappointing aspects of this study has been the failure of the city to use the information provided to them in their long range planning for the harbor. At the present time, city planners are attempting to have an extensive dredging project undertaken by the U.S. Army Corps of Engineers. They are also using CZM funds to redo work which has already been done by us, a number of other investigators and public agencies. It was our hope that the study would have been used to a greater extent than it actually has.

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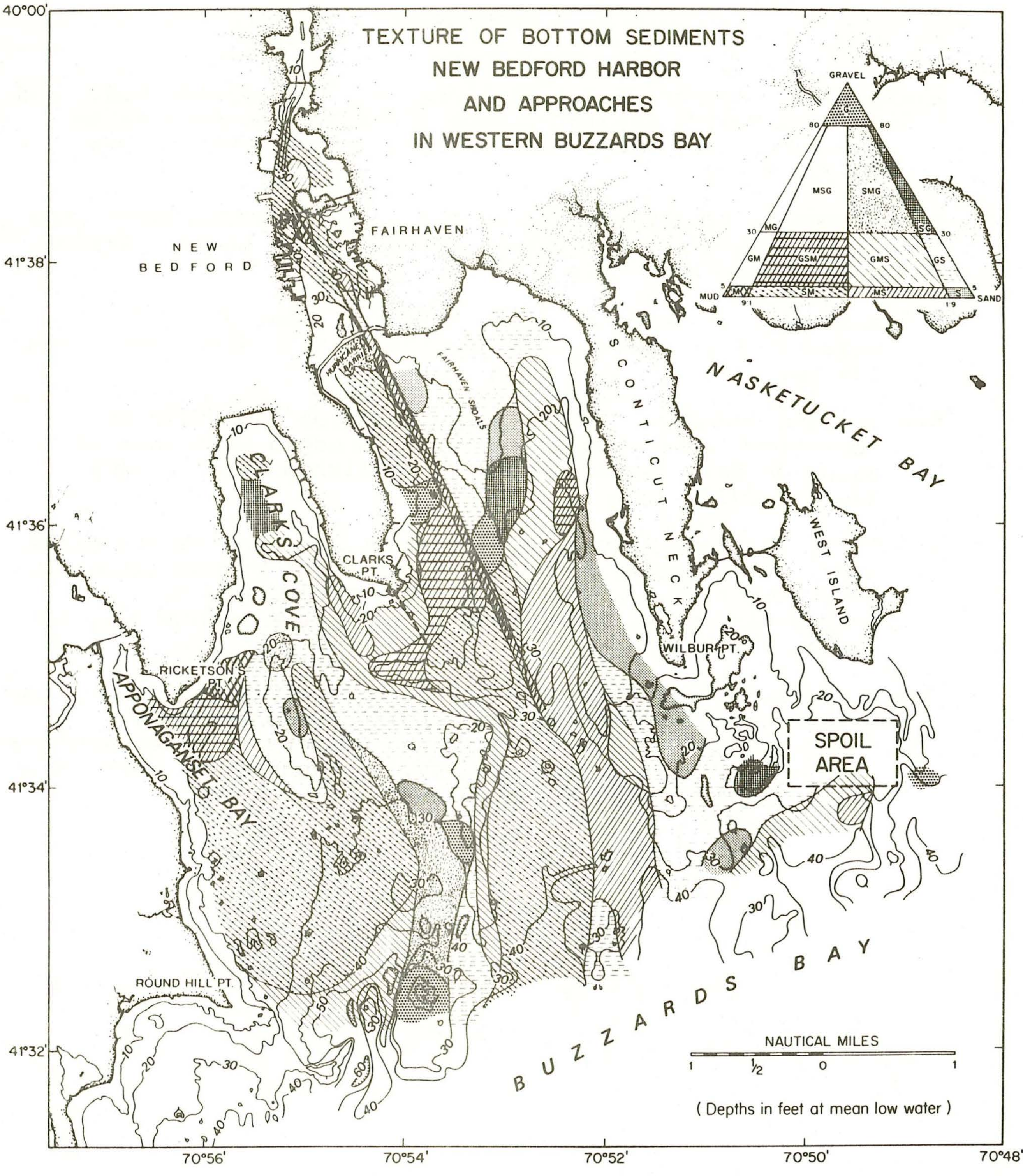

Figure 14. Textural classification of bottom sediments (after Folk 1968).

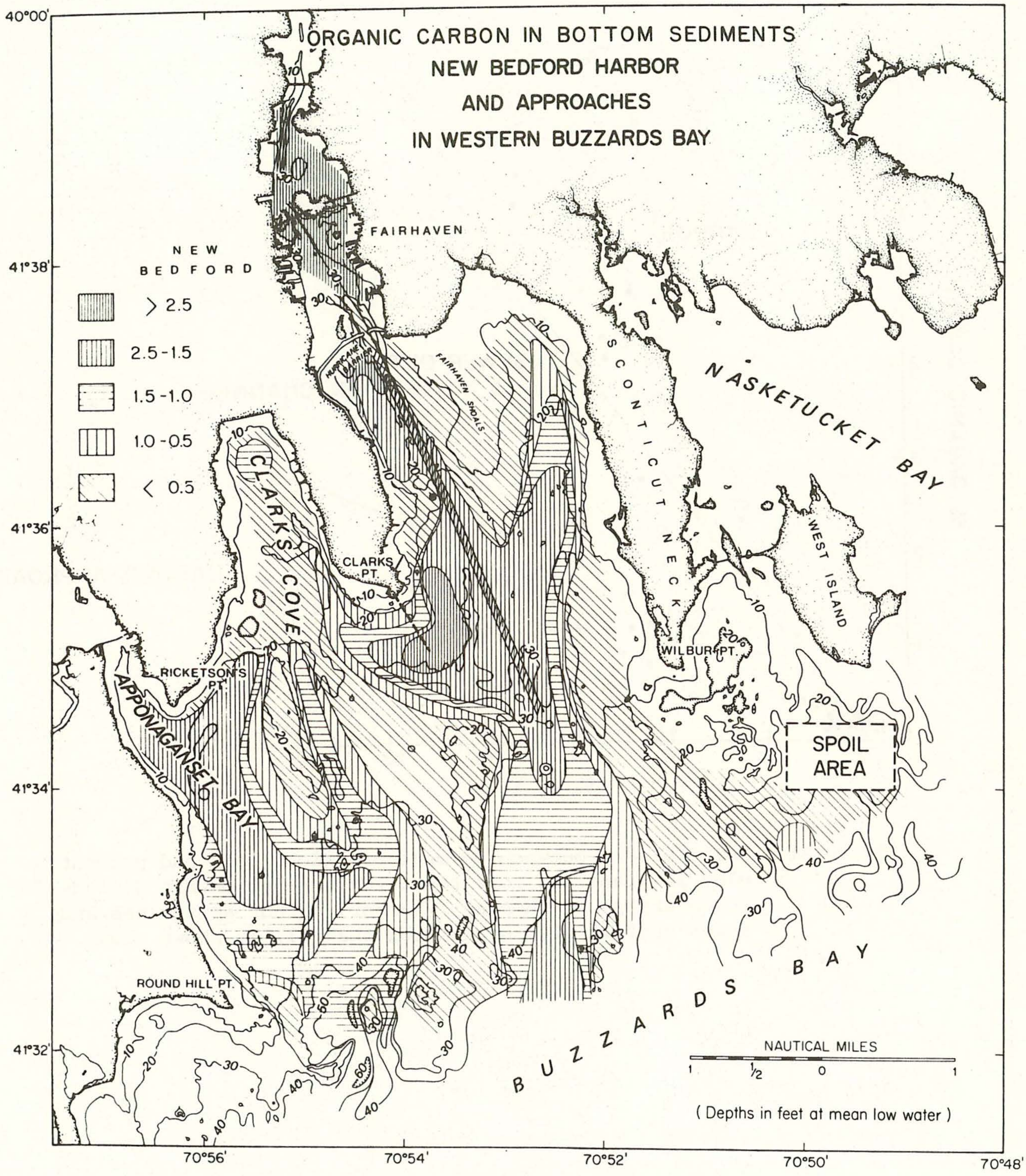

Figure 20. Percent organic carbon.

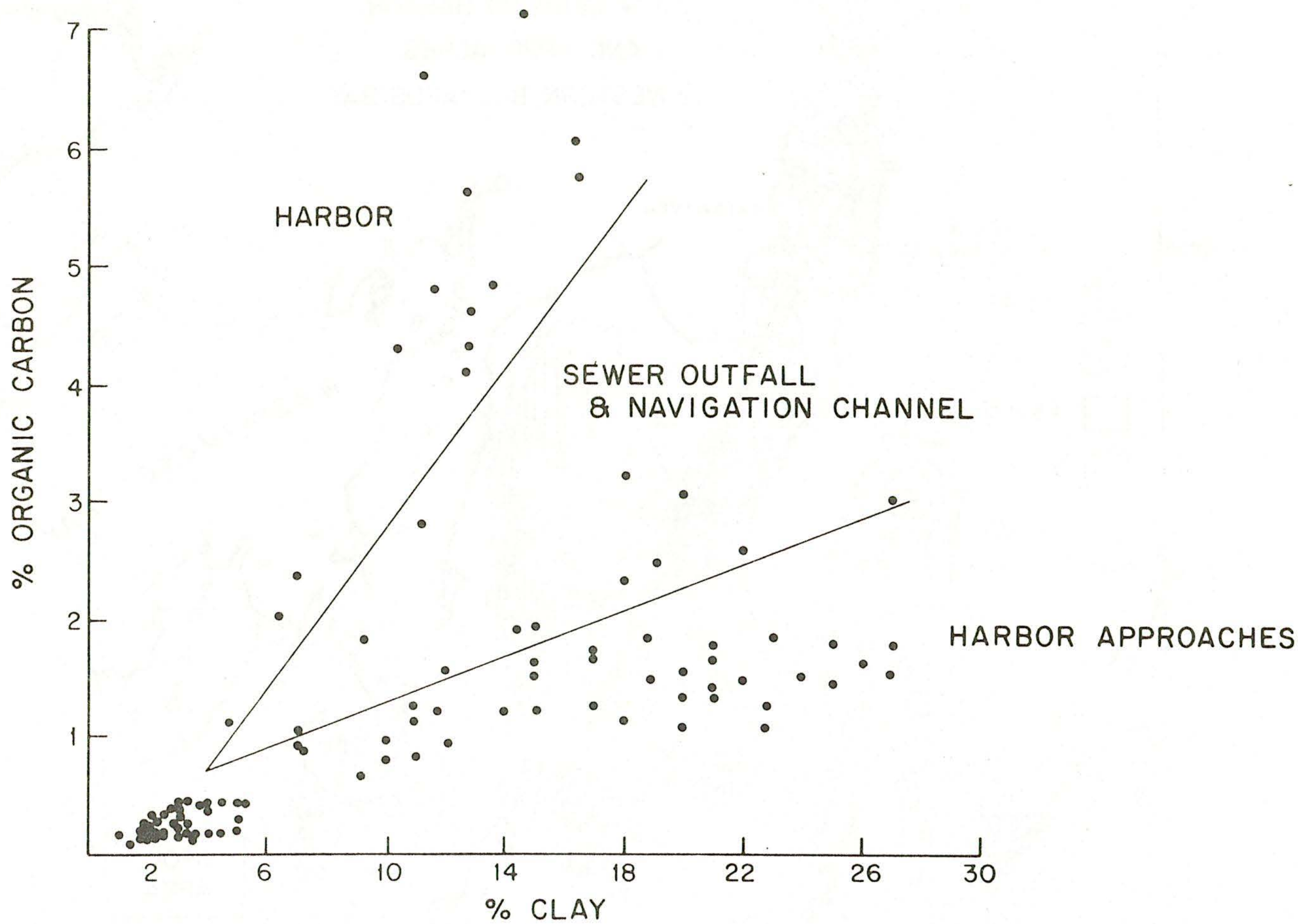

Figure 21. Relationship between percent organic carbon and percent clay in grabs and core tops. This relationship differs for three groups of samples: harbor, harbor approaches and sewer outfall plus navigation channel, as shown above.

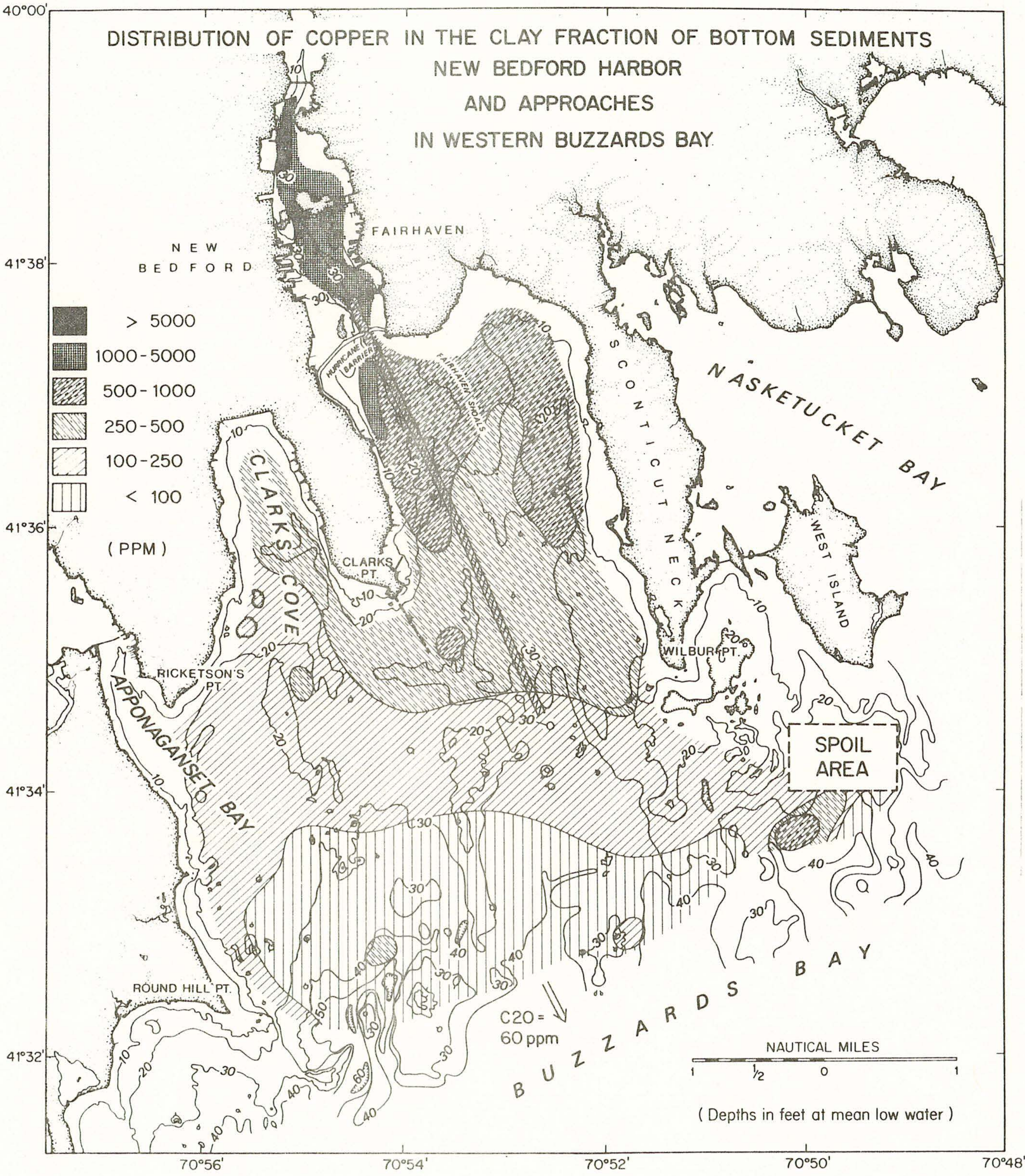

Figure 28. Regional Cu distribution based on surface sediment samples.

SEA LEVELS AND DEFORMATION OF THE GEOID

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Woods Hole Oceanographic Institution
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Sea-level changes during the Holocene are more complex on an ocean-wide basis than many coastal geologists have suspected. These changes are revealed by present depth of the shelf break, radiocarbon-dated shoreline indicators, and tide-gauge records. The many references to pertinent data have been listed by Emery and Uchupi (in preparation), and only the results and a few critical references are given here.

The depth of the shelf break around the Atlantic Ocean (Fig. 1) is not uniform but commonly ranges between 50 and 200 m for the continental shelves of North America, Europe, South America, and Africa. At high latitudes, however, the shelf break off northern North America and Europe reaches 400-m depth, and off southern South America and Africa it is at intermediate depths. One might attribute the deep shelf breaks of northern North America and Europe to sinking of a peripheral bulge of the crust after melting of glaciers. However, the deeper shelf breaks at high latitudes cannot be due to glacial weighting effects alone, because there was little Wisconsinan glaciation along the Atlantic coast of southern South America and none in southern Africa.

Sea-level depths at 3,000-year intervals plotted from radiocarbon dates of mollusks and other organisms that lived nearly intertidally and their present depths or elevations (Fig. 2) reveal a trend that is the reverse of Figure 1. Past sea levels are deep along the tropical and temperate coasts but far above present sea level at high latitudes. Thus during the Holocene the shelves at high latitudes have undergone considerable oceanward tilting, whether in northern North America and Europe or in southern South America and Africa where Wisconsinan glaciers were minor or absent. This relative sinking of coasts at low latitudes and rising at high latitudes during the Holocene is continuing, as indicated by tide-gauge records that span the past 30 to 180 years compiled by Lennon (1976). Average rates range between +4 and -10 mm/year in the area included by Figure 2.

Plotted in map form, the movements of land versus sea level during the past 6,000 years denote regions of relative depression versus ones of elevation, according to trend surfaces developed by Newman et al. (in press) (Fig. 3). Unfortunately, his data are incomplete for Africa, so the trend for at least the southwestern half of the continent must be ignored. The trend lines of land movement for North America and South America correspond closely with the areas where the geoid is depressed or elevated above the best-fitting ellipsoid of rotation (Fig. 4) taken from Gaposchkin (1974). Does this mean that vertical crustal movements of the continental margins are due more to increases in irregularity of the geoid or to turning of the geoid on its axis, rather than only to simple rebound of continental shelves under their loads of water produced by rise of sea level due to returned meltwater? If so, we must re-evaluate our thinking about whether an eustatic sea-level curve even can exist. Clearly also, continuation of the Holocene trend of changing relationship between land and sea level means that serious consideration must be given to effects of submergence and emergence of coastal zones upon preservation of present environments and upon plans for coastal constructions.

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FIGURE CAPTIONS

Fig. 1 Depths to shelf break at 100-km intervals along both sides of the Atlantic Ocean. From Emery and Uchupi (in preparation).

Fig. 2 Co-time lines of sea level at 3000-year intervals along both sides of the Atlantic Ocean. From Emery and Uchupi (in preparation).

Fig. 3. Relative movement in meters of land with respect to sea level during the past 6000 years. Adapted from Newman et al. (in press). Wide tabs denote boundaries of deeper than usual shelf break at high latitudes.

Fig. 4. Surface of geoid with respect to best-fitting ellipsoid in meters. Adapted from Gaposchkin (1974).

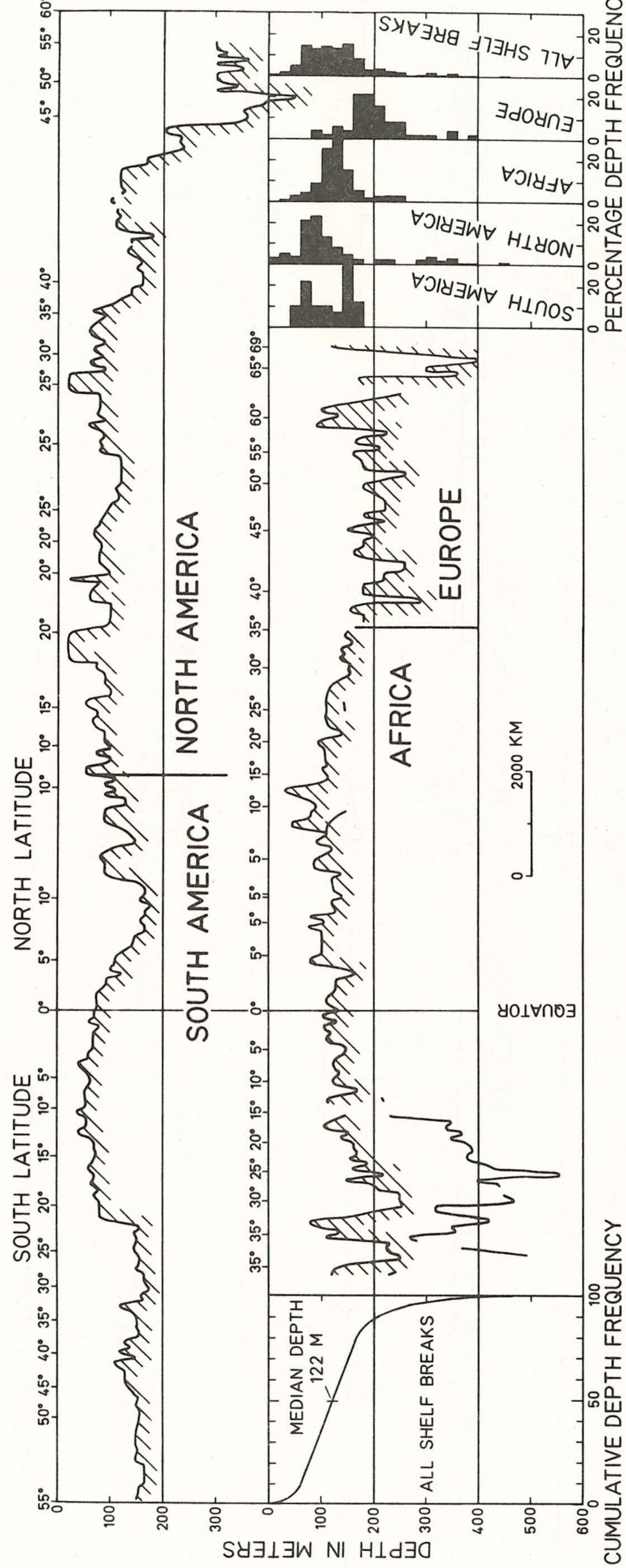

SOUTH LATITUDE
NORTH LATITUDE
SOUTH AMERICA
NORTH AMERICA
AFRICA
EUROPE
EQUATOR
2000 KM
DEPTH IN METERS
MEDIAN DEPTH 122 M
ALL SHELF BREAKS
CUMULATIVE DEPTH FREQUENCY
PERCENTAGE DEPTH FREQUENCY

Figure 1

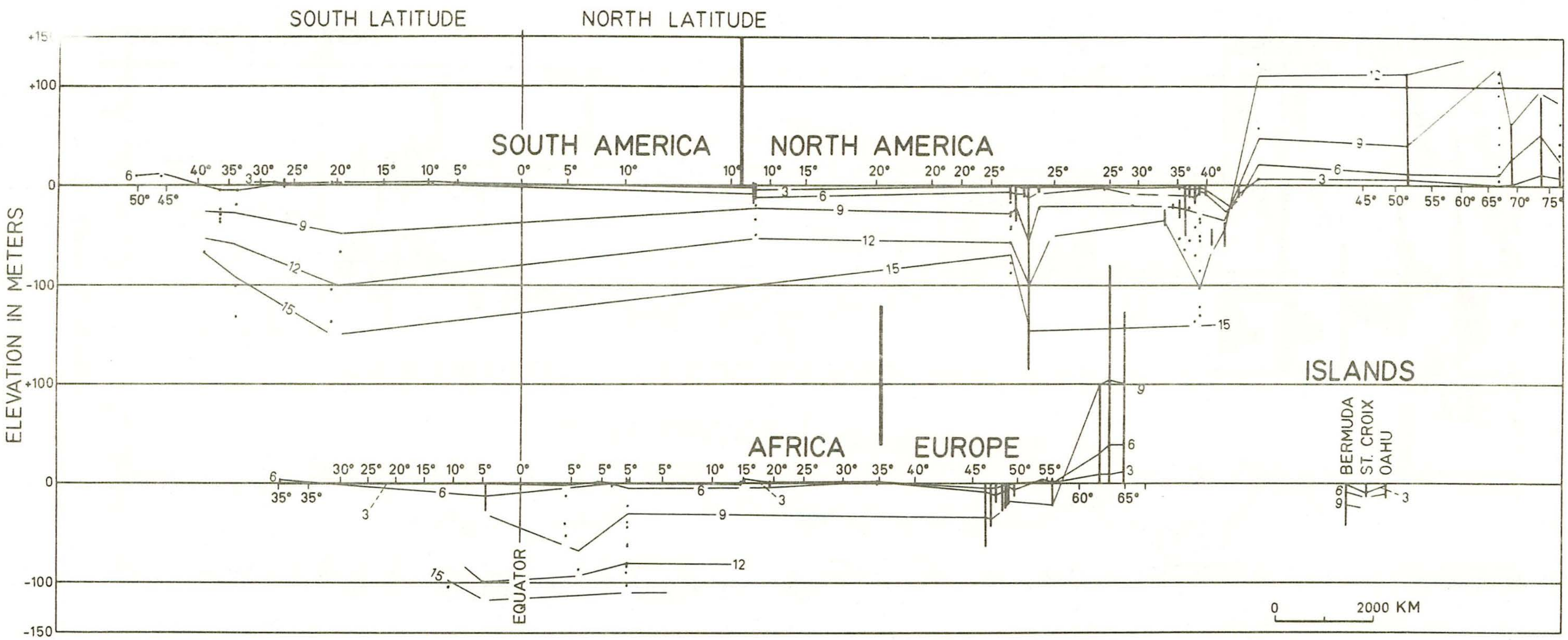

SOUTH LATITUDE
NORTH LATITUDE
SOUTH AMERICA
NORTH AMERICA
AFRICA
EUROPE
ISLANDS
BERMUDA
ST. CROIX
OAHU
EQUATOR
ELEVATION IN METERS
0
2000 KM

Figure 2

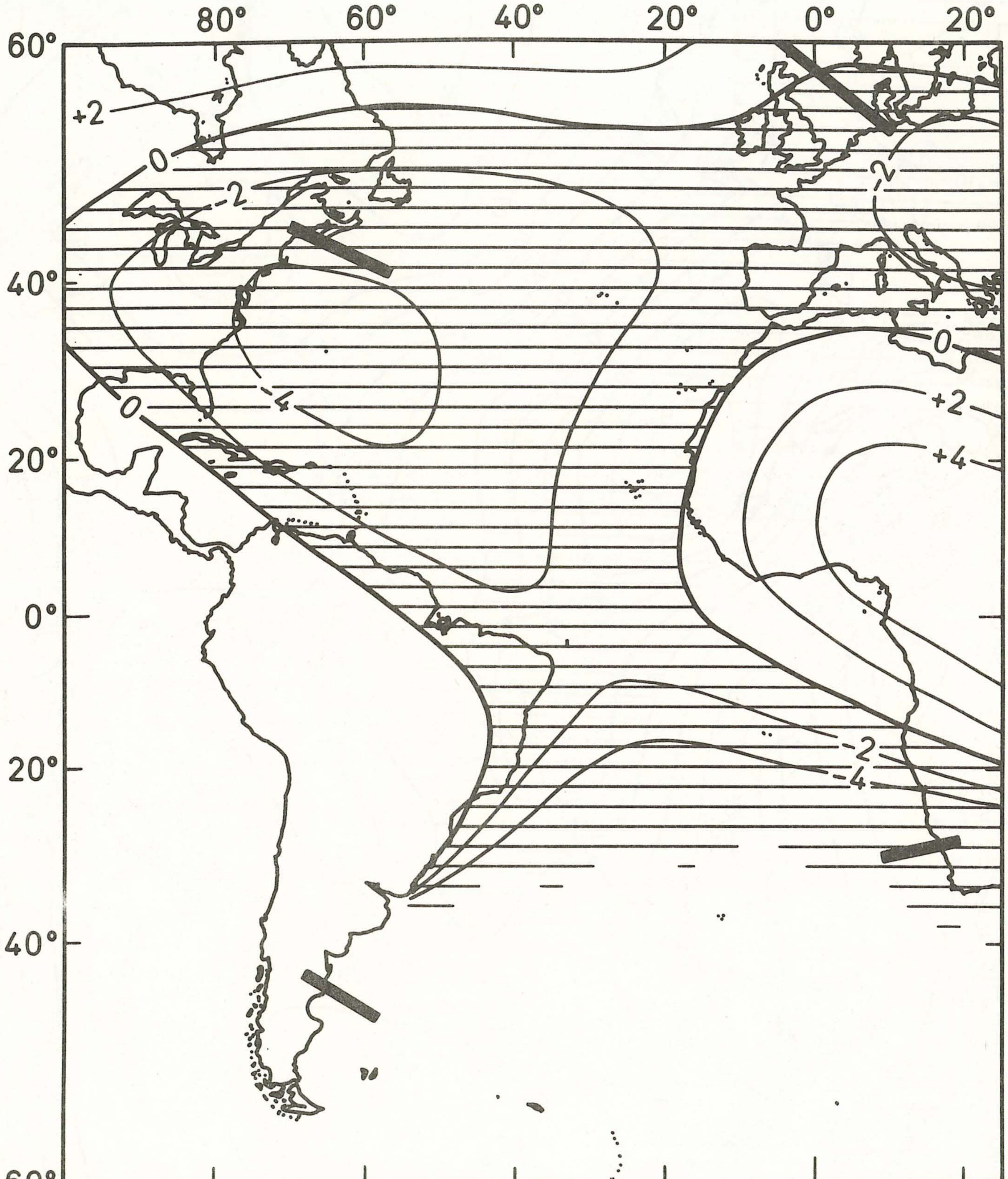
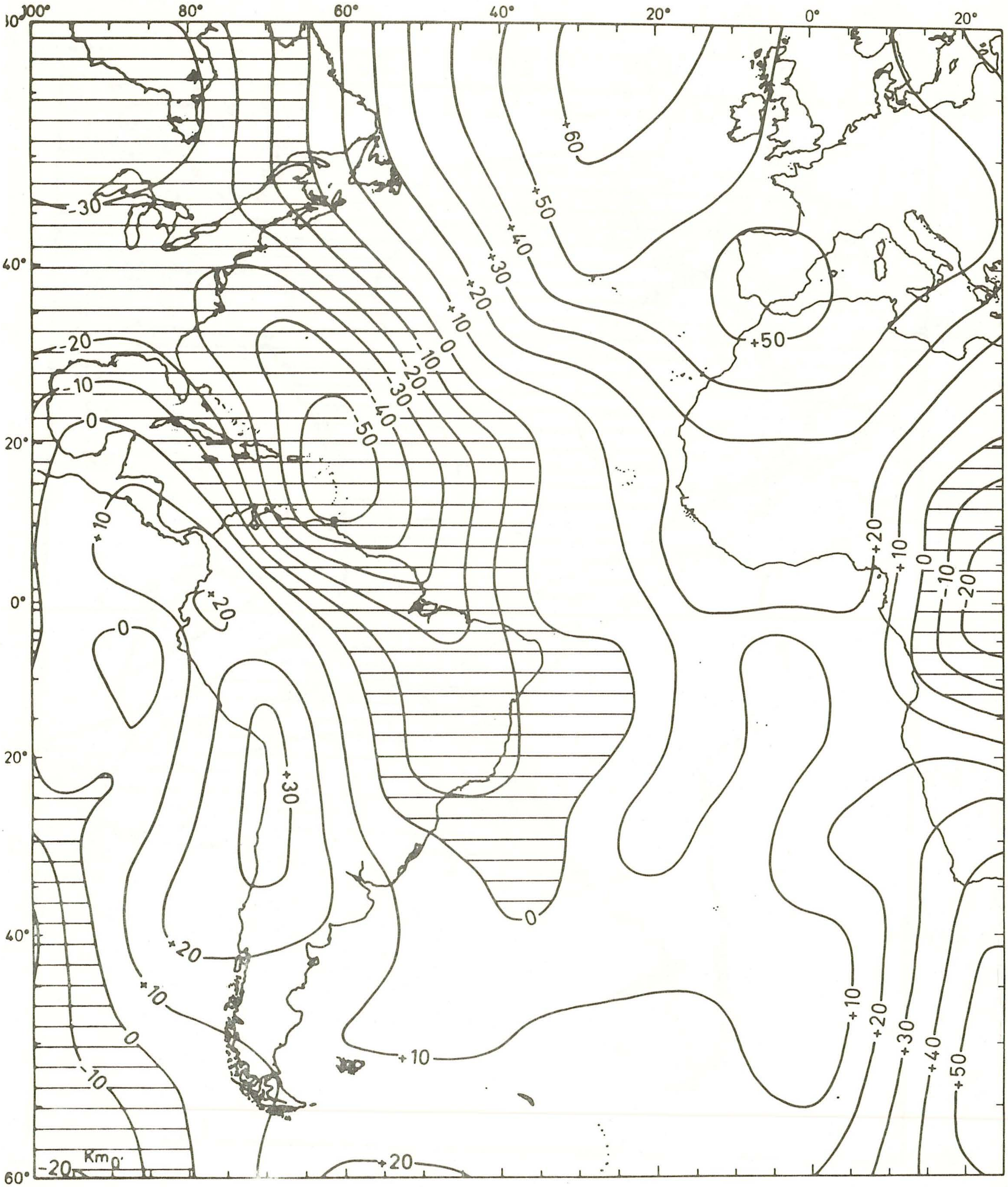


Figure 3.


100°
80°
60°
40°
20°
0°
20°
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20°
0°
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40°
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-30
+60
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-20
-10
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+10
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+30
+20
+10
0
-10
-20
Km
+20
+10
0
-10
-20
+10
+20
+30
+40
+50
+20

Figure 4.

AERIAL REMOTE SENSING SHORELINE CHANGE INVENTORY FOR MANAGEMENT PLANNING - NANTUCKET ISLANDS AND BOSTON HARBOR ISLAND, MASSACHUSETTS

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Detailed photogrammetric surveys from aerial photographs enables mapping of erosion and accretionary shoreline, duneline and cliffline changes over periods of time as great as 40 years. Quantitative values are developed which can be used for justification for storm zoning and hazard zone determination, construction set-back limits, sediment budget values for shore protection, structure designs, environmental impact statements and geologic coastal processes. Suitable federal vertical aerial photography is usually available at 5 year intervals for long-term trend studies, while the taking of recent small-frame format aerial photography of the study area with spring and fall as well as post-storm coverage will enable determination of the magnitude and location of short-term seasonal changes.

Photogrammetric techniques include field surveys for controls for scale determination to nearest 0.5 ft together with an optical microrule measuring to .001 inch enable mapping of shoreline feature positions to 1 meter. Seasonal field surveys in the specific study area of beach profile geometry, sediment characteristics and wave dynamics provide field data for long-term photogrammetric analysis. In the remote sensing laboratory the Bausch and Lomb Satellite Zoom Transfer Scope enables optical rectification of aerial photographs to ground control surveys as well as enlargement or reduction to a common scale. A digital planimeter enables accurate mapping of shoreline changes by area rather than by transect or dot grid. All sequential mapping is done on dimensionally stable acetate film to maintain accuracy.

The advantages of using remote sensing photogrammetric techniques together with ground field surveys are: less expensive than field surveys, aerial photographs show the exact location of the shoreline at a specific date and not an abstract generalized line as on a topographic map, aerial photographs show duneline, cliff scarplines as well as an almost unlimited amount of ground detail whereas map and charts show only selected detail. The above basic technique was developed and applied in 1975-77 to a Sea Grant funded study of the shoreline changes of the Rhode Island and Narragansett Bay shoreline by John J. Fisher as principal investigator. Using the above equipment it was applied to a similar study of the Nantucket shoreline by M. Goetz with J. Fisher as advisor (1978) and is presently being conducted by P. Riegler (1978-79) for the Boston Harbor Islands, again with J. Fisher as advisor, as part of an Earth Watch program under R. Jones, Boston State College who's providing the ground data surveys.

For the island of Nantucket some 215 survey stations at 1000 foot intervals were established covering the years 1938, 1951, 1961, 1970, in addition Landsat satellite photography for 1974 and 1976 were also examined for recent shoreline changes. Long-term (32 year) average erosion rates were found to be 0.56 m/yr. for the eastern shore, 2.11 m/yr. for the southern shore, 0.1 m/yr for the north shore west of the inlet while accretion at 0.72 m/yr was east of the inlet along the north shore. A sediment budget analysis of these changes indicates that of the material eroded from the shoreline only 10 percent appears to be deposited as accretionary features, the remainder appear to be deposited offshore in shoals.

Following are figures and tables showing examples of typical long-term shoreline change inventory parameters as developed by this photogrammetric remote sensing technique for Nantucket Island, Massachusetts. Note: Not all data tables of this inventory are presented.

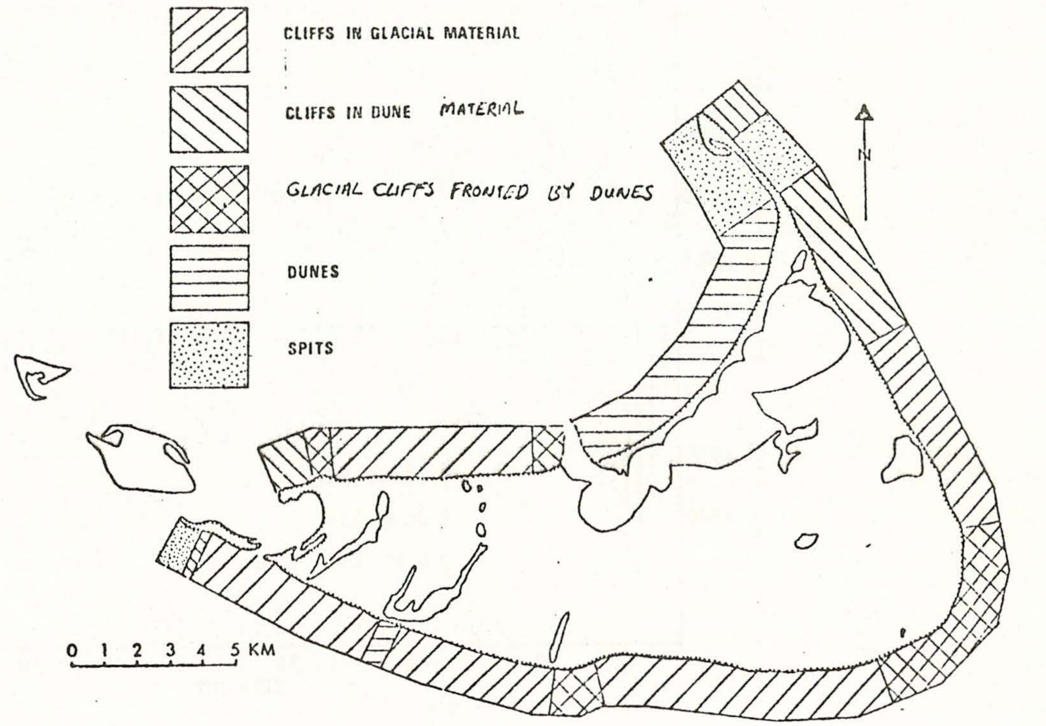

Fig. 1. Shoreline Types.

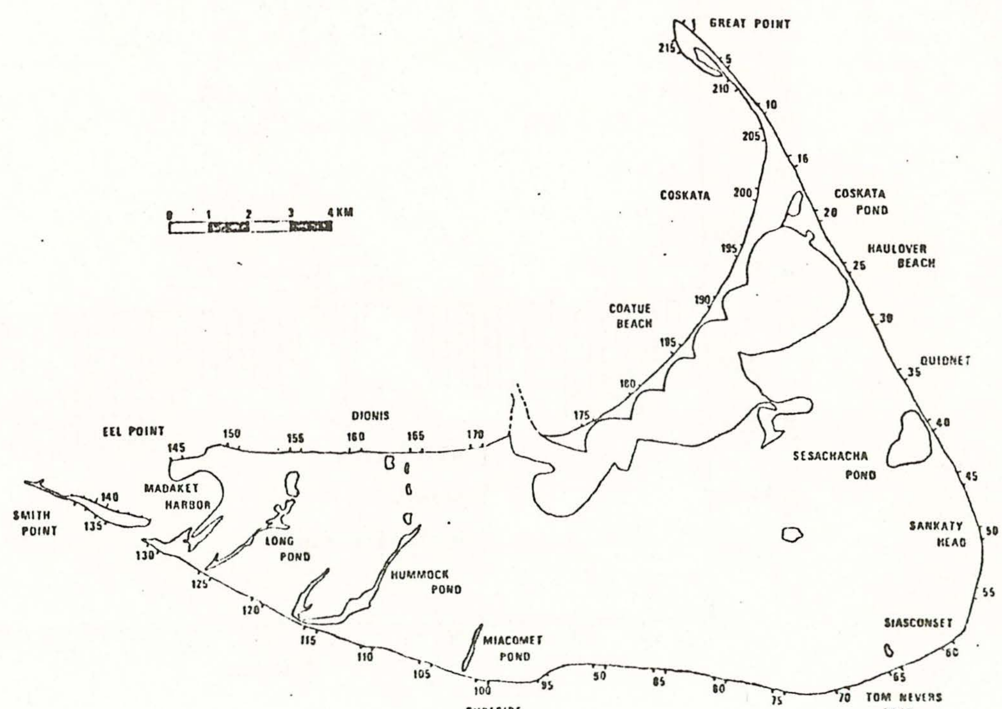

Fig. 2. Shoreline Segments.

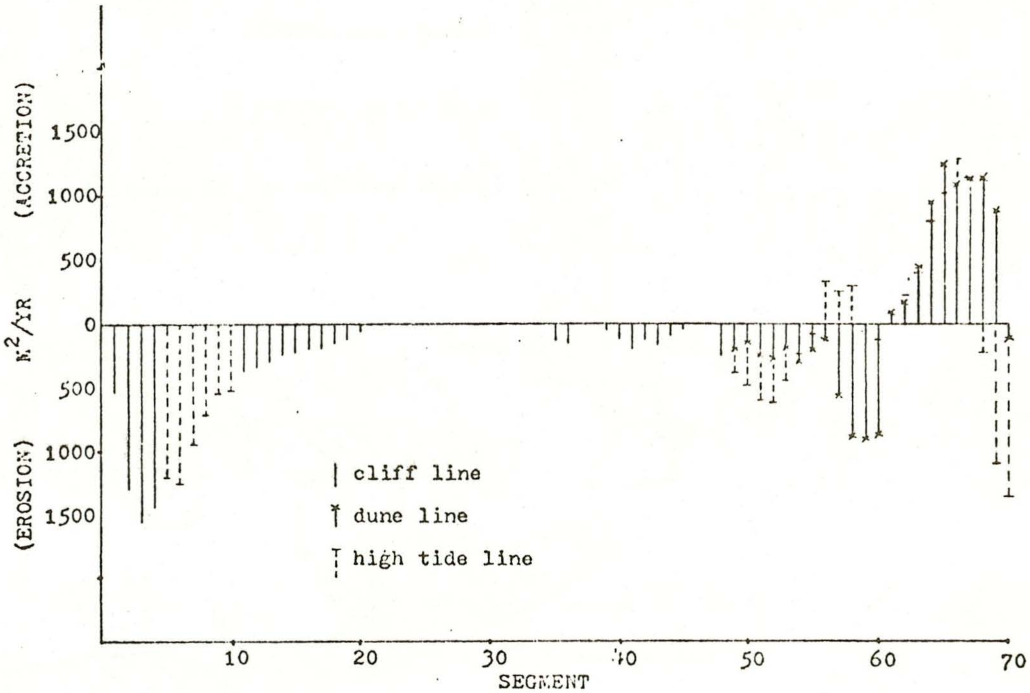

Fig. 3. Annual Change 1938 - 1970.
Great Point to Tom Nevers Head.

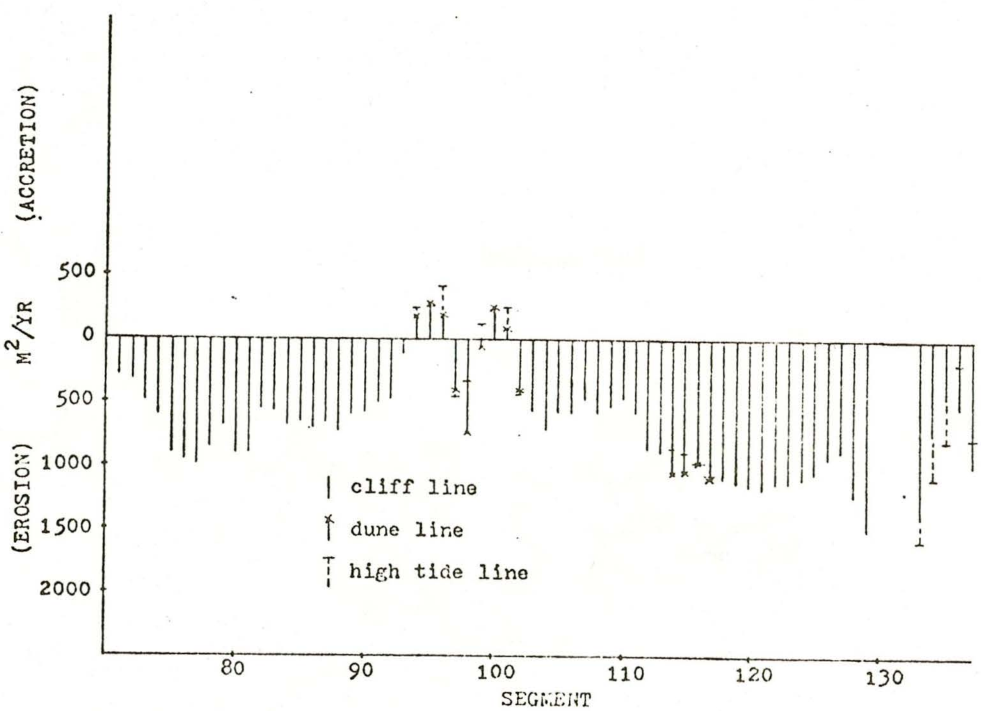

Fig. 4. Annual Change 1938 - 1970.
Tom Nevers Head to Smith Point.

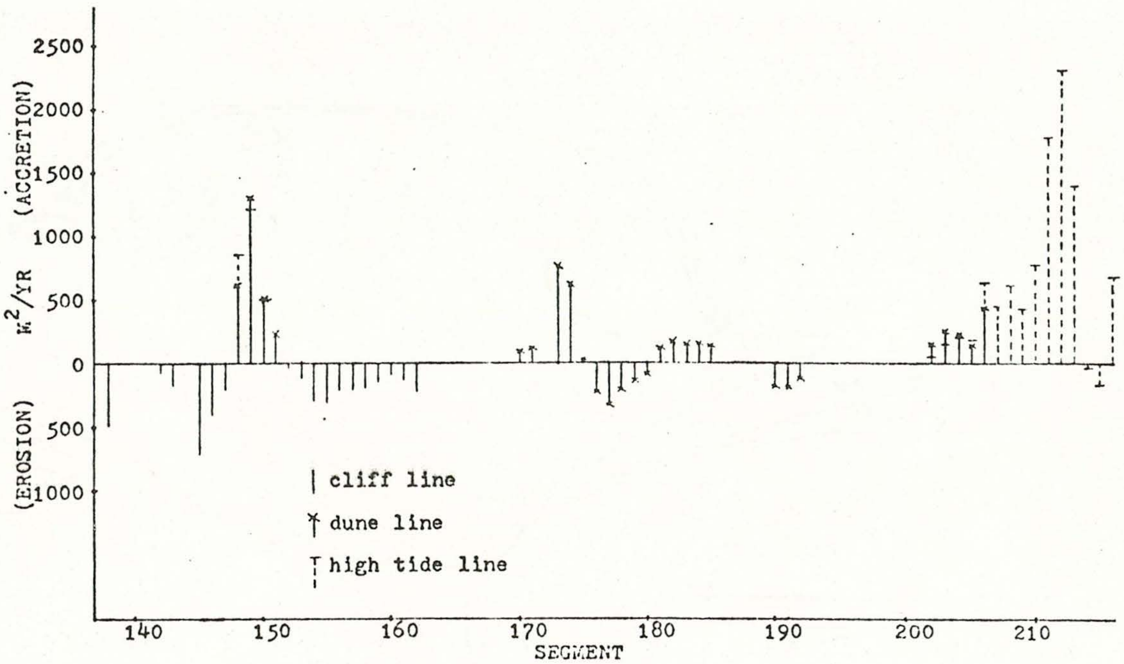

Fig. 5. Annual Change 1938 - 1970.
Smith Point to Great Point.

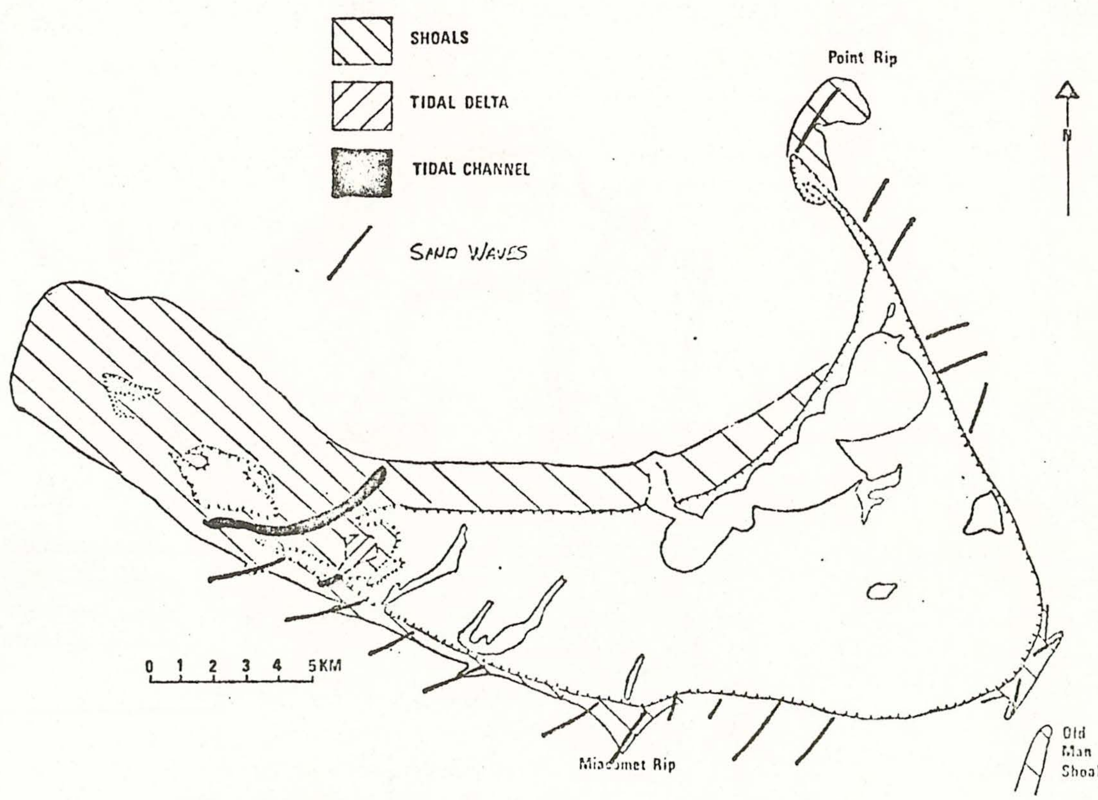

Fig. 6. Nantucket Shoals and other nearshore depositional features mapped from aerial photographs and satelite photography.

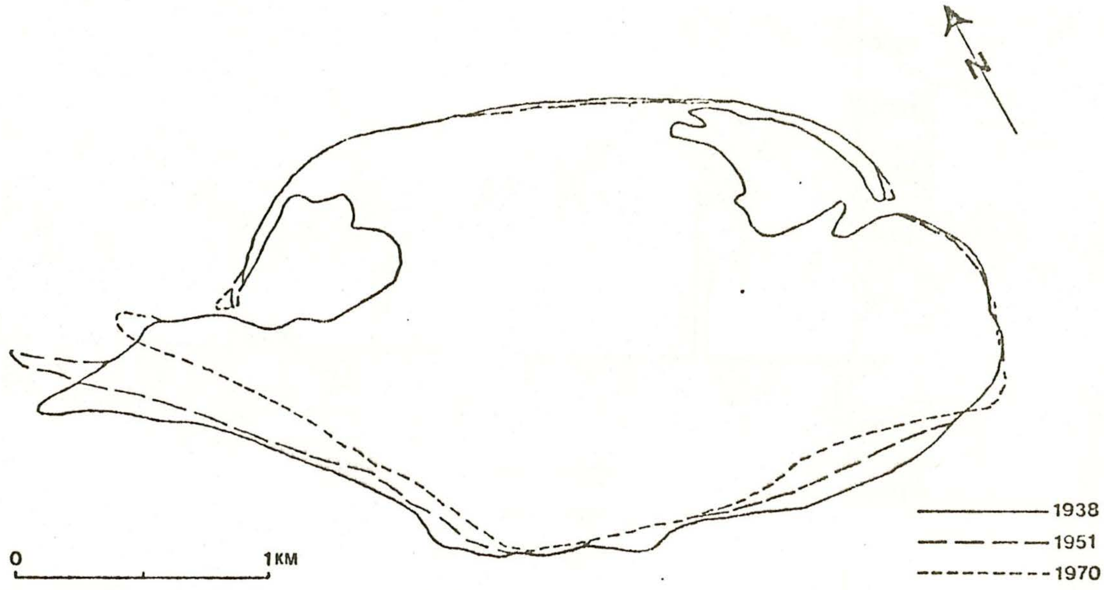

Fig. 7. Shoreline Changes 1938 - 1970.
Muskegat Island.

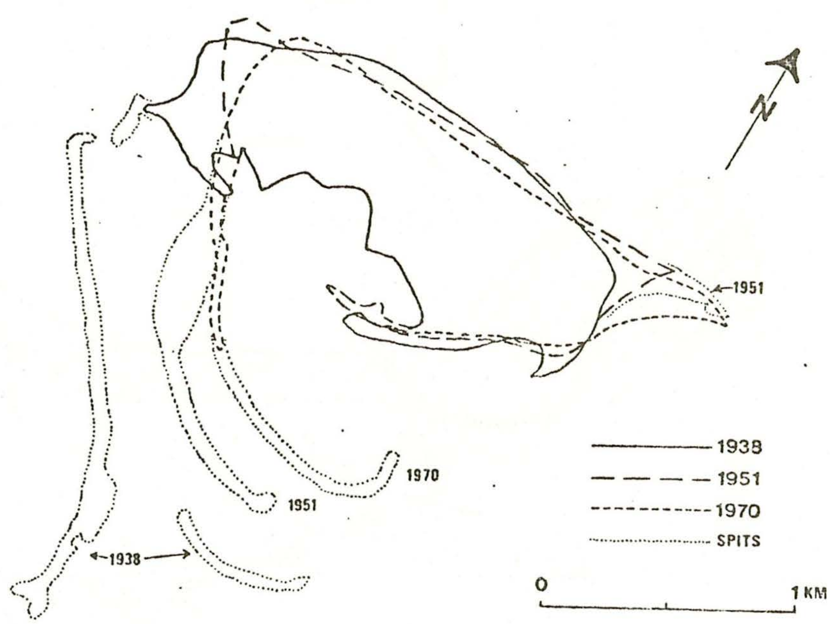

Fig. 8. Shoreline Changes 1938 - 1970.
Tuckernuck Island.

Table I
Example of
Mean Annual Shoreline Changes (m^2/yr)

Cliff Line Segments

	1938-1951	1951-1961	1961-1970
1	-410.3	-630.4	-682.4
2	-621.6	-1,879.5	-1,683.2
3	-1,442.3	-1,653.2	-1,611.3
4	-1,889.9	-1,007.7	-1,269.0
11	-920.1	-	-
12	-733.5	-	-134.7
13	-733.5	-	-26.9
14	-410.3	-	-305.3
15	-348.2	-	-314.3
16	-298.4	-	-305.3
17	-298.4	-	-305.3
18	-198.9	-	-251.4
19	-124.3	-	-287.3
20	-62.2	-	-53.9
21-34	-	-	-
35	-321.4	-	-
36	-346.1	-	-
37	-	-	-
38	-	-	-
39	-	-128.5	-
40	-173.1	-	-142.8
41	-278.1	-	-303.6
42	-129.8	-	-241.0
43	-99.2	-	-430.6
44	-	-	-344.0
45	-	-	-126.8
46	-	-	-
47	-	-	-
48	-	-	-659.3
71	-	-259.7	-721.4
72	-349.6	-	-634.8
73	-599.3	-	-865.7
74	-665.2	-259.7	-937.8
75	-699.2	-727.2	-1,370.7
76	-958.9	-864.8	-749.2

Table I (cont.). Example of
Mean Annual Shoreline Changes (m^2/yr)

Dune Line Segments

	1938-1951	1951-1961	1961-1970
64	2,297.3	-	72.1
65	3,995.4	-43.1	-865.7
66	4,345.0	-2,207.5	72.1
67	3,645.8	-1,688.1	721.3
68	3,146.4	-	-461.7
69	1,498.3	519.4	505.0
70	99.9	-519.4	-
94	481.9	-	-
95	766.5	-	-
96	704.3	-256.3	-
97	-123.1	-1,798.3	803.1
98	-889.6	-1,412.8	284.8
99	-185.3	-	143.5
100	-	-	899.5
101	-74.1	-	481.9
114	-803.4	-1,305.5	-1,064.7
115	-954.0	-1,480.4	-652.8
116	-1,958.2	-783.3	-290.1
117	-1,958.2	-1,305.5	435.1
118	-1,004.2	-1,436.0	-774.6
148	303.9	1,487.2	-180.8
149	1,394.2	836.6	1,626.7
150	268.0	395.0	955.3
151	357.5	167.3	68.1
170	-	259.3	-
171	-	389.0	-
172	-	-	-
173	1,003.1	625.9	579.6
174	230.7	195.6	579.6
175	-266.9	-	463.9
176	-421.3	-	-173.9
177	-351.1	-	-623.0
178	-240.8	-	-335.4
179	-355.0	-	-
180	-230.9	-	115.9
181	-100.3	-	579.6
182	-	-	623.0
183	120.4	-	362.2
184	371.2	-	-
185	351.7	-	-
186-189	-	-	-
190	-432.1	-	-
191	-462.2	-	-

Table I (cont.). Example of
Mean Annual Shoreline Changes (m^2/yr)

High Tide Line Segments

	1938-1951	1951-1961	1961-1970
116	-1,339.6	-1,044.4	-
117	-1,225.6	-1,370.8	-145.1
118	-1,054.5	-1,391.7	-725.3
133	-1,233.5	-801.8	-2,869.3
134	-1,182.1	-400.9	-1,632.0
135	-1,593.3	588.0	-1,231.4
136	-616.8	1,870.8	-1,854.6
137	-349.5	1,069.0	-3,486.4
148	769.3	1,176.1	592.7
149	1,128.4	1,920.2	518.6
150	307.7	888.1	340.8
151	-	-	-
202	-	182.9	-
203	-	483.3	-
204	-	653.1	-
205	60.3	522.5	-
206	1,055.1	130.6	580.6
207	1,692.1	-870.0	194.4
208	2,311.1	-1,024.1	-
209	2,411.5	-1,332.4	-435.4
210	2,276.9	-104.5	-386.1
211	1,674.0	1,175.6	2,612.6
212	1,523.3	3,069.7	2,612.6
213	2,130.2	347.5	1,524.0
214	823.9	-1,502.2	435.4
215	134.6	-1,502.2	899.9
216	-	-	2,444.1

Table II
Example of
Composite Annual Shoreline Change (m^2/yr)

Cliff Line Segments

1.	- 555.6	71.	- 284.1	126.	- 912.6
2.	-1,313.3	72.	- 320.6	127.	- 893.5
3.	-1,555.8	73.	- 486.9	128.	-1,224.3
4.	-1,439.6	74.	- 615.2	129.	-1,502.2
11.	- 373.9	75.	- 496.8	* 130.	-1,562.5
12.	- 335.9	76.	- 964.3	* 131.	-1,552.5
13.	- 305.6	77.	-1,014.5	* 132.	-1,552.5
14.	- 252.6	78.	- 858.6	133.	-1,483.7
15.	- 229.9	79.	- 673.2	134.	- 730.3
16.	- 207.1	80.	- 905.3	135.	- 345.3
17.	- 207.1	81.	- 909.3	136.	- 521.6
18.	- 151.5	82.	- 545.9	137.	- 980.6
19.	- 131.3	83.	- 568.3	138.	- 476.7
20.	- 40.4	84.	- 677.2	139.	-
21.	-	85.	- 648.3	140.	-
22.	-	86.	- 704.4	141.	-
23.	-	87.	- 652.3	142.	- 66.8
24.	-	88.	- 725.3	143.	- 146.2
25.	-	89.	- 593.0	144.	-
26.	-	90.	- 573.9	145.	- 726.2
27.	-	91.	- 502.1	146.	- 391.8
28.	-	92.	- 466.3	147.	- 217.8
29.	-	93.	- 122.0	152.	- 40.9
30.	-	102.	- 411.4	153.	- 101.7
31.	-	103.	- 549.9	154.	- 290.5
32.	-	104.	- 701.7	155.	- 292.9
33.	-	105.	- 571.2	156.	- 225.1
34.	-	106.	- 577.7	157.	- 222.8
35.	- 130.6	107.	- 469.1	158.	- 192.2
36.	- 140.6	108.	- 571.1	159.	- 137.7
37.	-	109.	- 517.3	160.	- 82.5
38.	-	110.	- 448.8	161.	- 96.5
39.	- 40.2	111.	- 571.1	162.	- 226.8
40.	- 110.5	112.	- 856.7	163.	-
41.	- 198.3	113.	- 883.7	164.	-
42.	- 120.5	119.	-1,113.3	165.	-
43.	- 161.4	120.	-1,150.7	166.	-
44.	- 96.8	121.	-1,183.0	167.	-
45.	- 35.7	122.	-1,134.1	168.	-
46.	-	123.	-1,134.1	169.	-
47.	-	124.	-1,086.8		
48.	- 241.9	125.	-1,030.3		

* (Estimate of composite annual change for breached segments)

Table II (cont.). Example of Composite Annual Shoreline Changes (m^2/yr)

Dune Line Segments

49.	- 208.0	98.	- 722.8	183.	150.8
50.	- 161.3	99.	- 34.9	184.	150.8
51.	- 249.9	100.	252.9	185.	142.9
52.	- 282.2	101.	105.4	186.	-
53.	- 201.6	114.	-1,033.8	187.	-
54.	- 282.2	115.	-1,033.8	188.	-
55.	- 181.4	116.	- 958.7	189.	-
56.	- 120.9	117.	-1,081.1	190.	- 175.5
57.	- 564.4	118.	-1,074.6	191.	- 187.8
58.	- 811.5	148.	639.0	192.	- 108.6
59.	- 892.7	149.	1,285.3	193.	-
60.	- 852.1	150.	501.0	194.	-
61.	97.4	151.	216.7	195.	-
62.	178.5	170.	81.0	196.	-
63.	452.9	171.	121.6	197.	-
64.	953.6	172.	-	198.	-
65.	1,244.9	173.	766.1	199.	-
66.	1,095.6	174.	635.7	200.	-
67.	1,156.5	175.	27.7	201.	-
68.	1,148.4	176.	- 220.1	202.	169.0
69.	913.0	177.	- 317.8	203.	273.5
70.	- 121.7	178.	- 206.2	204.	236.8
94.	195.8	179.	- 136.1	205.	138.8
95.	311.4	180.	- 81.5	206.	454.7
96.	205.0	181.	122.3		
97.	- 386.1	182.	175.2		

High Tide Line Segments

5.	-1,192.5	64.	784.8	133.	-1,558.7
6.	-1,254.7	65.	1,020.9	134.	-1,064.5
7.	- 930.3	66.	1,322.8	135.	- 809.9
8.	- 728.6	67.	1,164.6	136.	- 187.5
9.	- 544.6	68.	- 231.3	137.	- 788.5
10.	- 524.5	69.	-1,108.6	148.	846.8
49.	- 384.6	70.	-1,334.2	149.	1,204.3
50.	- 463.6	94.	242.2	150.	498.4
51.	- 586.4	95.	276.1	202.	57.2
52.	- 616.8	96.	423.8	203.	151.0
53.	- 456.2	97.	- 437.5	204.	204.1
54.	- 241.9	98.	- 322.9	205.	187.8
55.	- 88.7	99.	113.0	206.	632.7
56.	332.8	100.	213.9	207.	470.2
57.	243.5	101.	264.0	208.	618.8
58.	284.0	102.	433.5	209.	440.8
59.	- 48.7	114.	- 856.7	210.	783.8
60.	- 125.8	115.	-1,019.9	211.	1,782.2
61.	-	116.	- 870.6	212.	2,312.9
62.	223.2	117.	- 966.9	213.	1,402.6
63.	409.8	118.	-1,067.3	214.	- 12.3

SURF ZONE - TIDAL INLET INTERATION

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The transition zone between the wave - dominated open coast and the tide - dominated inlet mouth has been studied for the past two years. Field studies were conducted on the Florida coast at Johns Pass and Matanzas Inlet during January, 1977 and at Matanzas Inlet in July and August, 1978. A time - series study was done at each inlet to determine the relationship between wave processes and tidal currents and the response of ebb tidal delta and beach to changes in wave and tide conditions.

The tidal currents were monitored by six moored current meters which were moved at one week intervals. The velocity and direction of the tidal current one meter above the bottom were recorded at 15 minute intervals. The meters were placed at several positions in the ebb and flood channels, and in the surf zone outside the ebb tidal delta. Bi-plane drogues which were tracked by transits on shore were used to plot the surface current velocities at different times during the tidal cycle. Tidal current velocities were also monitored simultaneously at five locations across the mouth of the inlet by suspending flow meters from the bridge. A Fourier analysis was used to smooth the tidal current curves and to extract the wave and tide components from the meter records. Velocity contour maps plotted for each stage of the tide will be used in conjunction with bathymetric maps to compute wave refraction diagrams for the vicinity of the tidal inlet. The ebb and flood currents which flow with or against the incoming waves influence the wave refraction pattern.

Four times each day, waves and longshore currents were measured in the surf zone locations on each side of the inlet. During the winter of 1977, the waves approached Matanzas Inlet from the northeast generating a longshore current which flowed to the south. The longshore current reinforced the flood current on the north side of the inlet, and the ebb current on the south side. During July and August, 1978, the waves approached Matanzas Inlet from the southeast and formed a northward flowing longshore current. During the summer the ebb tidal delta was skewed to the north by the longshore currents. Benno Brenninkmeyer and a group of students from Boston College also set up an instrument array at two locations in the surf zone to measure wave and current spectra, and suspended sediment.

The response of the beach and ebb tidal delta to waves and currents was determined by mapping the area at weekly intervals. A series of ten profiles extending across the beach and nearshore bars provided data for the map series. The shoal areas were mapped by transit surveys and a fathometer was used to plot the positions and depths of the tidal channels. The velocity and discharge will be computed for each of the major tidal channels in the ebb tidal delta.

The field studies will be used as a basis for a computer simulation model of the ebb tidal delta. The current pattern will be portrayed by a series of velocity contour maps for different stages of the tide. Wave refraction maps will provide an estimate of the distribution of wave energy within the area. The interaction of tidal and longshore currents will be computed at every tidal state under different wave conditions to predict the pattern of sediment distribution in the vicinity of the tidal inlet. The model will be used to predict the evolution of the ebb tidal delta and changes in its morphology based on wave climate and tidal regime.

HISTORICAL OVERVIEW OF STUDIES OF PHYSICAL PROCESSES IN THE MASSACHUSETTS COASTAL ZONE

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The history of physical coastal research in Massachusetts follows the history of the development of techniques for the observation and measurement of coastal characteristics and phenomena. Seventeenth century navigation permitted visits and descriptions of the Massachusetts coast by such explorers as Samuel Champlain and John Smith. During the eighteenth century the development of surveying instruments and techniques had sufficiently advanced so that Joseph DesBarres was able to present in his Atlantic Neptune, prepared for the British Admiralty during the 1770's and 1780's, the first accurate and detailed charts of the Massachusetts coast. In the nineteenth century the U.S. Coast Survey (founded in 1807) improved upon and completed the accurate coastal charting of Massachusetts under the guidance of such men as Henry Mitchell, Henry Whiting, and Henry Marindin. During this period coastal physical processes were the concern of the physiographers who, lacking the means of direct measurement, deduced processes from studies of the accurate charts which were becoming available. Thus, C. D. Davis in 1849 proposed that such depositional features as the Provincetown Hook and the Chatham east coast barrier beaches resulted from the transport of sand by tidal currents; Henry Mitchell (1875) correctly interpreted the role of waves as the primary agent responsible for the supply of sediment to the Chatham barrier beaches; William Morris Davis (1896) explained the growth and development of the Provincelands Hook; and Douglas Johnson (1925) discussed many Massachusetts coastal forms and their development in his book The New England-Acadian Shoreline.

The twentieth century brought development of the techniques of sediment sampling and analysis and such investigators as John Hough, Marshall Schalk, and Francis Shepard began the description of our coastal sediments. Also, beginning in Boston in 1921, and in Woods Hole in 1932, the U.S. Coast and Geodetic Survey began a long-term series of measurements of tidal elevations and sea levels. World War II brought for the first time techniques for the actual measurement of nearshore processes. The need to predict short-term shore changes for amphibious operations and the development of electronics, making possible field measurements of nearshore processes, were powerful stimulants to modern investigation. At the Woods Hole Oceanographic Institution, Henry Stetson initiated coastal studies which were continued after his death by John Zeigler and which led to field measurements of nearshore flow as well as sediment characteristics. Miles Hayes at the University of Massachusetts established the Coastal Science Center and initiated similar studies, while at M.I.T. Arthur Ippen and Peter Eagleson initiated mathematical and laboratory studies of nearshore hydrodynamics.

The recent history of coastal research in Massachusetts indicates a rapid enlargement in the scale and complexity of studies, perhaps reflecting the development of high-speed computers and earth reconnaissance satellites. We now consider the coast to be more than the boundary between the land and the sea. We speak of the "coastal zone," a distinct environment which lies between the marine (or aquatic) environment and the terrestrial environment, a kind of membrane which both separates and joins those two major divisions of the biosphere. For this reason, coastal physical processes are more frequently being studied as part of interdisciplinary investigations of this complex environment.

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REMARKS

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Before discussing my present work on coastal submergence, I will mention some other studies with which I am presently concerned and some that I have made in the past which relate directly to subjects which have been discussed. Of the latter, one concerned the shape sorting of beach pebbles and indicated that on predominantly sandy beaches the "rollability" of pebbles plays an important role in their shape sorting in the swash zone. Another dealt with the rate of cliff retreat on the east coast of Cape Cod and indicated that the rate at any one point is very irregular, proceeding rapidly for a few years and slowly for periods of 10 or 20 years. Many of my studies in the recent past have been designed to provide information useful to local communities in making coastal management decisions. An example of such studies is my recently completed study of the barrier beaches of Chatham, Massachusetts.

At present, I am concerned with a study of Pamet Inlet in Truro which is aimed in part at determining the extent to which dikes across portions of the Pamet River system have reduced the tidal prism and consequently the size of the inlet. A study at Pilgrim Beach in Truro deals with the mechanisms responsible for the large accumulations of "seaweed" in the area. In Provincetown Harbor, I have observed significant episodes of upwelling and I am presently investigating their characteristics.

CAUSES OF MASSACHUSETTS SHORELINE RETREAT

Graham S. Giese

Two major processes are primarily responsible for shoreline retreat in Massachusetts: erosion due to sediment transport by waves, and submergence by a rising relative sea level. Of the two, submergence is the more important.

A simple model of shoreline change as a result of relative sea level change is illustrated in Fig. 1. Here the coastal margin for a distance, L, along the coast is represented as an uneven surface with a mean seaward inclination, Θ, while the sea surface is a horizontal plane surface. The line formed by the intersection of the two surfaces is the "shoreline," ℓ. A right-handed rectangular coordinate system is applied to an arbitrary point, P, along ℓ such that the x and y axes are horizontal and directed seaward and alongshore respectively, and the z direction is vertically upwards. Θ_p represents the local seaward inclination of the coast at p.

If dx/dt is the rate of shoreline advance/retreat, then the rate of horizontal land surface area (A) emerged or submerged is given by:

$$\frac{dA}{dt} = \int_0^{\ell} \frac{dx}{dt}\, dy. \qquad [1]$$

Assuming that dx/dt is determined solely by the rate of change of relative sea level, dz/dt, and the slope, Θ_p, we can write:

$$\frac{dx}{dt} = \cot \Theta_p \left(\frac{dz}{dt}\right).$$

Substituting this expression into equation [1], we have:

$$\frac{dA}{dt} = \frac{dz}{dt} \int_0^{\ell} (\cot \Theta_p)\, dy.$$

Since,

$$\int_0^{\ell} (\cot \Theta_p)\, dy = (\ell)\, \overline{\cot \Theta_p},$$

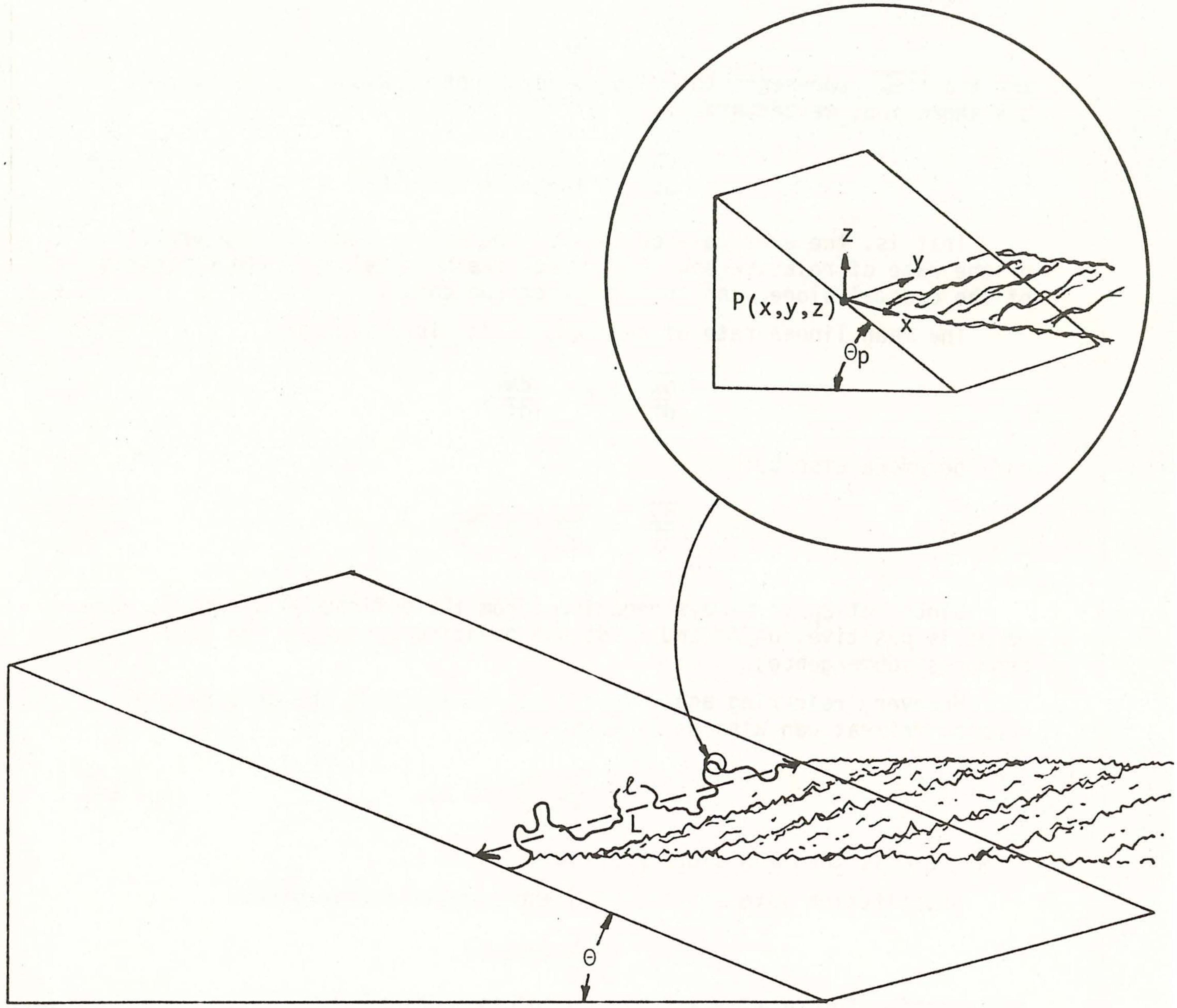


FIGURE 1

where $\overline{\cot \Theta_p}$ represents the mean value of $\cot \Theta_p$ along the length, ℓ, of the shoreline, we can write:

$$\frac{dA}{dt} = \left(\frac{dz}{dt}\right) (\ell) (\overline{\cot \Theta_p}). \qquad [2]$$

That is, the area rate of coastal retreat is given by the product of the rate of relative sea level rise, the mean value of the cotangent of the coastal slope, and the length of the coast.

The mean linear rate of retreat, $\overline{dx}/dt$, is given by:

$$\frac{\overline{dx}}{dt} = \ell^{-1} \left(\frac{dA}{dt}\right),$$

and therefore also by:

$$\frac{\overline{dx}}{dt} = \frac{dz}{dt} (\overline{\cot \Theta_p}). \qquad [3]$$

Since $\cot \Theta_p$ is always negative (from the definition diagram), when dz/dt is positive, dA/dt and $\overline{dx}/dt$ are negative (relative sea level rise produces submergence).

However, referring again to Fig. 1, we see that the area rate of coastal retreat can also be expressed by:

$$\frac{dA}{dt} = \frac{dz}{dt}(L)(\cot \Theta), \qquad [4]$$

in which Θ is the mean slope perpendicular to L.

Substitution into equation [2] and simplification gives:

$$\overline{\cot \Theta_p} = \frac{L}{\ell} (\cot \Theta),$$

and substitution of this expression into equation [3] yields:

$$\frac{\overline{dx}}{dt} = \frac{dz}{dt}\left(\frac{L}{\ell}\right) (\cot \Theta). \qquad [5]$$

Thus the mean linear rate of shoreline retreat is given by the product of the rate of relative sea level rise, the ratio of overall coastal length to actual shoreline length, and the cotangent of the overall coastal slope.

While submergence and emergence result from relative sea level changes, erosion and accretion result from sediment transportation processes. If Q_y denotes the instantaneous volume rate of alongshore sediment transportation across a shore of width, W, and Q_x denotes the volume rate of offshore sediment transportation across a length of shore equal to W, then the net rates, $\overline{Q}_x$ and $\overline{Q}_y$, of offshore and alongshore transport over a time interval, t, are given by:

$$\overline{Q}_x = \frac{1}{t}\int_0^t Q_x dt$$

$$\overline{Q}_y = \frac{1}{t}\int_0^t Q_y dt.$$

Considering the role of $\overline{Q}_y$, the rate of change of volume alongshore for distance ℓ is given by:

$$\left(\frac{dV}{dt}\right)_y = \int_0^{\ell}\left(-\frac{d\overline{Q}_y}{dy}\right)dy = \left(-\overline{\frac{d\overline{Q}_y}{dy}}\right)\left(\ell\right),$$

in which $\overline{d\overline{Q}_y/dy}$ is the mean value along ℓ of the alongshore gradient of $\overline{Q}_y$.

The rate of change of area is given by the above expression divided by the "active depth", D, of the shore:

$$\left(\frac{dA}{dt}\right)_y = \left(-\frac{\ell}{D}\right)\left(\overline{\frac{d\overline{Q}_y}{dy}}\right).$$

Considering the role of $\overline{Q}_x$, the rate of change of volume for distance ℓ is given by:

$$\left(\frac{dV}{dt}\right)_x = \left[\int_0^{W}\left(-\frac{d\overline{Q}_x}{dx}\right)dx\right]\left(\frac{\ell}{W}\right) = \left(-\overline{\frac{d\overline{Q}_x}{dx}}\right)\left(W\right)\left(\frac{\ell}{W}\right) = \left(-\overline{\frac{d\overline{Q}_x}{dx}}\right)\left(\ell\right).$$

Again, as above, the rate of change of area is given by dividing this expression by D:

$$\left(\frac{dA}{dt}\right)_x = \left(-\frac{\ell}{D}\right)\left(\overline{\frac{d\overline{Q}_x}{dx}}\right).$$

Combining the two expressions yields:

$$\left(\frac{dA}{dt}\right)_{\substack{\text{sediment}\\ \text{transport}}} = \left(\frac{dA}{dt}\right)_x + \left(\frac{dA}{dt}\right)_y = \left(-\frac{\ell}{D}\right)\left(\overline{\frac{d\overline{Q}_x}{dx}} + \overline{\frac{d\overline{Q}_y}{dy}}\right).$$

This may then be combined with equation [4] to give:

$$\frac{dA}{dt} = \left[\left(\ell\right)\left(\frac{L}{\ell}\right)\left(\frac{dz}{dt}\right)\left(\cot\Theta\right)\right]_{\substack{\text{sea}\\\text{level}}} + \left[\left(-\frac{\ell}{D}\right)\left(\frac{d\overline{Q}_x}{dx}+\frac{d\overline{Q}_y}{dy}\right)\right]_{\substack{\text{sediment}\\\text{transport}}} .$$

The area retreat rate per unit length of shoreline is then:

$$\frac{1}{\ell}\left(\frac{dA}{dt}\right) = \left[\left(\frac{L}{\ell}\right)\left(\frac{dz}{dt}\right)\left(\cot\Theta\right)\right]_{\substack{\text{sea}\\\text{level}}} + \left[\left(-\frac{1}{D}\right)\left(\frac{d\overline{Q}_x}{dx}+\frac{d\overline{Q}_y}{dy}\right)\right]_{\substack{\text{sediment}\\\text{transport}}} ,$$

or:

$$\frac{1}{\ell}\left(\frac{dA}{dt}\right) = \left[\left(\frac{L}{\ell}\right)\left(\frac{dz}{dt}\right)\left(\cot\Theta\right)\right]_{\substack{\text{sea}\\\text{level}}} + \left[\left(-\frac{1}{D}\right)\left(\nabla\cdot\vec{Q}\right)\right]_{\substack{\text{sediment}\\\text{transport}}} ,$$

in which:

$$\vec{Q} \equiv \overline{Q}_x\,\hat{i} + \overline{Q}_y\,\hat{j} .$$

Fig. 2 illustrates types of shoreline forms which would result from combinations of these terms given zero, positive and negative values. C_1, C_2, and C_3 apply to Massachusetts coast where relative sea level is rising.

Perhaps 90% of the Massachusetts shoreline lies along the "inner" coast—shorelines of bays, estuaries, marshes and tidal creeks—where sediment transport is negligible ($Q_x \simeq 0$, $Q_y \simeq 0$), because there is insufficient wave energy to transport appreciable quantities of sediment. For these regions the rate of shoreline retreat is given by equations [4] and [5].

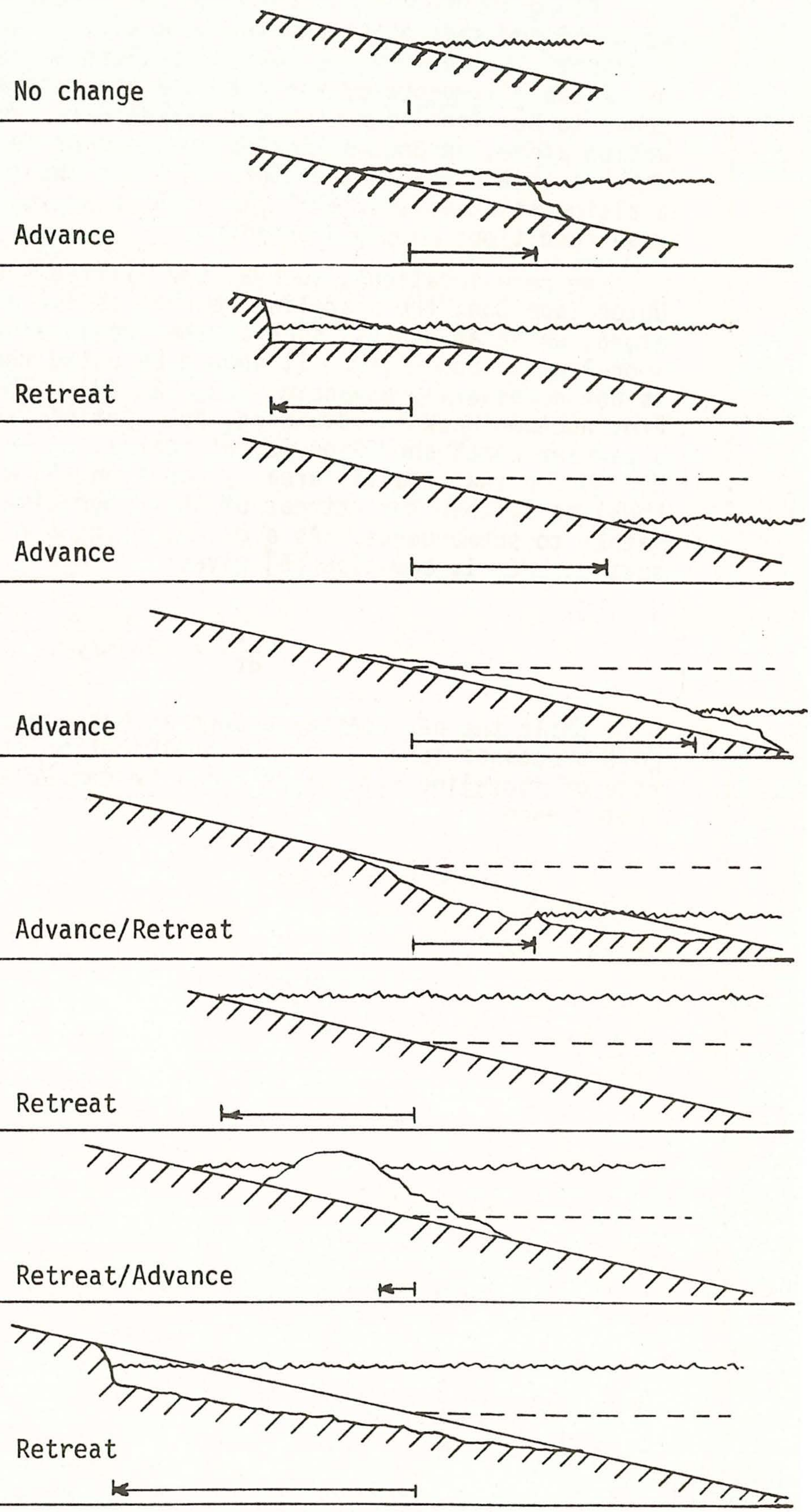
As values for the variables, we will let $dz/dt = 3$ mm/yr., $\cot\Theta = 200$, $L/\ell = 0.1$, and $L = 1$ km. Then, the area rate of retreat is given by equation [4]:

$$\frac{dA}{dt} = (3\times10^{-3}\text{m/yr})(10^{3}\text{m})(200) = 600\text{m}^2\text{/yr per kilometer},$$

and the mean linear retreat rate is given by equation [5]:

$$\frac{\overline{dx}}{dt} = (3\times10^{-3}\text{m/yr})(0.1)(200) = 0.06\text{m/yr}.$$

CLASS	SEA LEVEL TERM	SEDIMENT TRANSPORT TERM	SHORE PROFILE
A1	0	0	No change
A2	0	+ Accretion	Advance
A3	0	- Erosion	Retreat
B1	+ Emergence	0	Advance
B2	+ Emergence	+ Accretion	Advance
B3	+ Emergence	- Erosion	Advance/Retreat
C1	- Submergence	0	Retreat
C2	- Submergence	+ Accretion	Retreat/Advance
C3	- Submergence	- Erosion	Retreat



F I G U R E 2

Along shores which do receive appreciable wave energy, the absolute value of the sediment transport term will be small if the net rate of transport is small ($\overline{Q} \simeq 0$), as it is along shorelines bounded by headlands; or if the divergence of the net rate of transport is small ($\nabla \cdot \overline{Q} \simeq 0$), as it tends to be along long straight shorelines. Under the influence of wave action alone, an unconsolidated coast tends to develop shoreline forms which approach one or the other of these two stable conditions. However, a rising relative sea level disrupts an approach to stability by altering wave conditions at the shoreline.

At some locations, such as the cliffed shorelines of Manomet and Outer Cape Cod, the shoreline retreat is due almost entirely to erosion alone, while at others, such as the Provincetown Hook and Sandy Neck, the shoreline is accreting. It should be noted that an accreting shoreline is not necessarily advancing (Fig. 2, C2). The outer shoreline of the Provincetown Hook is advancing, but that of Sandy Neck is retreating. If a barrier beach shoreline is not retreating as rapidly as would be predicted for that coastal area by equation [5] with the ratio, L/ℓ, set equal to 1, then the retreat of that shoreline is not due to erosion, but rather to submergence. As a guide, using the values given earlier, but setting $L/\ell = 1$, equation [5] gives:

$$\overline{\frac{dx}{dt}} = 0.6\text{m/yr.}$$

While the net coastal change in Massachusetts due to sediment transport processes is erosion, the contribution of this erosion to the total rate of shoreline retreat is small in comparison to the contribution of submergence.

WAVE-CURRENT INTERACTIONS IN THE COASTAL ZONE

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The urgency of the need to improve our knowledge of the coastal zone and its associated dynamics has been brought to the forefront in the past several years due to an increase in man's activities in the coastal zone. In response to this need, a research program in coastal hydrodynamics and sediment transport has been developed at the Woods Hole Oceanographic Institution. The summary presented here briefly describes some of the background and experiments which comprise that part of the research program dealing with the important problem of combined surface gravity waves and coastal currents acting over a movable boundary. This specific problem was picked for discussion purposes because a proper study of combined waves and currents must deal with a large number of temporal and spatial scales which are important to many processes of interest in the coastal zone. The emphasis here is on the small scale aspects of the problem, both from a hydrodynamic and areal viewpoint, and it is hoped that this summary will foster interaction with investigators who are involved in the larger scale parts of the problem.

It is easy to motivate a study of combined surface waves and currents in the context of sediment transport. Typical coastal currents are not capable of initiating sediment motion by themselves. On the other hand, waves, with their large associated boundary shear stress, are capable of transporting large amounts of sediment but are ineffective as a transporting mechanism (Madsen and Grant, 1976). To the first order, no net transport results due to waves. However, the presence of even a weak current with the wave motion will result in a net sediment transport. In addition, when the critical boundary shear stress is exceeded, bedforms develop on the sea bed, e.g., wave formed ripples. These bedforms play a critical role in the dynamics of the flow field near the bed, since the spatially varying pressure field associated with their presence results in a net force against the fluid, i.e., form drag. The resulting flow resistance influences the shape of the velocity profile, particularly in the vicinity of the sea bed. In natural flows, the adjustment of the boundary geometry to the flow is continually evolving, and an understanding of the flow dynamics at length and time scales relevant to sediment transport requires a detailed understanding of the fluid sediment interaction involved in the bedform generation. A more complicated twist to this problem involves potential self-stratification of the flow due to the suspended sediment load.

Along with the consideration of the fluid sediment interaction, there is also the problem of the interaction between the wave and the current in the region of the boundary. We are interested in the influence of currents on waves since we want to be able to accurately predict the wave characteristics at a given nearshore location from knowledge of deep water wave conditions. We are also interested in the influence of the wave on the current, since this will determine the magnitude of the "mean" flow, which transports the sediment once it is suspended from the bed. Recent theoretical work indictes that the presence of waves increases the flow resistance experienced by the current (Grant and Madsen, 1978).

The picture presented above, of waves and currents over a movable bed, sounds quite complicated, and it is. The interactions we must deal with are non-linear in nature, and in general do not lend themselves easily to sophisticated mathematical models. Nonetheless, recent theoretical work by Grant and Madsen (1977, 1978) and Smith (1977) has attempted to model combined wave and current flows in the presence of a rough boundary. The simple analytical models which result from this work are helpful at least in planning experiments designed to increase our knowledge of this important process in sediment transport in the coastal zone. The availability of such guidance is noteworthy since, at the present time, no data base exists from either the laboratory or the field which can be used, for example, to test the validity of the application of basic closure schemes or the resulting flow models.

Keeping in mind the background discussion given above, it is clear that the first task which had to be addressed in our research was the development of an experimental program which could provide such a data base. Due to the incompatibility of Froude and Reynolds number scaling laws, and to the problems involved in building a flume with sufficiently "clean" wave and current flows, we decided on an experimental field program. It is convenient to describe the measurements involved in this program in the context of a simple physical model which identifies, in a crude sense, the important length and time scales involved in the combined wave and current problem. The predominant feature that any study of combined waves and currents must deal with is the range of length and time scales associated with the respective fluid motions. The relatively steady current, with its associated boundary layer (i.e., the region where the shear associated with the current is important), developed over most of the depth of the flow in the absence of stratification. This contrasts sharply with the unsteady oscillatory wave motion, with its associated boundary layer region limited to the immediate vicinity of the sea bed due to its short time scale. At the boundary itself, the presence of wave formed ripples introduces another important length scale, the physical boundary roughness which is related in a complicated manner to the hydrodynamic roughness experienced by the flow. (An additional contribution to the hydrodynamic roughness can result from intense bed load transport, see Smith, 1977.) In addition, right at the boundary, the shear stress (which is generally referred to as skin friction) is related to the grain diameter.

For typical surface waves, e.g., 4 to 14 seconds, the wave boundary layer thickness would be in the range of 2 to 15 centimeters and a maximum ripple height of the same order of magnitude would be expected. Thus, in coastal waters ranging in depth from tens of meters to 100 meters, the range of length scales which must be dealt with covers four orders of magnitude, even with the neglect of the sediment grain scale.

This wide range of spatial scales must be accurately resolved in order to make calculations of Reynolds stress profiles as well as to determine the instantaneous velocity profiles, which are two desired products of our experimental studies. Practical considerations of data processing suggest the use of two different sampling rates inside and outside the wave boundary layer region. Furthermore, the larger scale volume averaged velocity measurements which are permissible away from the bed cannot resolve the flow structure in the immediate vicinity of the bed, i.e., primarily the wave boundary layer region. This problem is overcome by employing two different velocity sensors. These current meters are the Acoustic Travel Time Sensor (ACM) developed by Albert J. Williams at the Woods Hole Oceanographic Institution, e.g., see Williams and Tochko (1976), and a Lasar Doppler Velocimeter (LDV) also developed by Williams, e.g., see Terry and Williams (1977). A more in-depth summary of these instruments is given in the proceedings of this workshop by Williams, who is a co-principal investigator in this research.

Briefly, the ACM is a volume averaging type of sensor which allows the determination of the average velocity over a 15 cm path by measuring three orthogonal velocity components. Since the most energetic eddies scale essentially as the distance from the sheared boundary, the ACM cannot resolve any length scales closer than 30 cm from the bottom, i.e., no measurements can be made in the wave boundary layer region. Below the 30 cm level, the LDV must be used; for the purposes of discussion here, the LDV may be considered as a point measurement device. With this scheme, instantaneous velocity measurements at 30, 50, 100, and 200 cm above the sea bed can be made using four ACM's stacked in the vertical (the sampling rate is approximately 8 Hz). Velocity measurements can be made below the 30 cm level, simultaneously with ACM measurements above, using the LDV (for data processing reasons, 10 Hz is a realistic cut-off frequency). Due to the high sampling rates, continuous in situ data recording is limited to 2 hours with the ACM. At the present time, the LDV is hardwired to a surface recording system.

It is important to bring attention to another aspect of the length scale problem: the problem of spatial variability in the cross stream and down stream direction. Recent experimental studies at the Woods Hole Oceanographic Institution and by other investigators, e.g., McLean and Smith (1978), illustrate the large horizontal variability which can exist in the mean vertical velocity profile and the Reynolds stress profiles. This variability can result from the influence of local topography as well as a high turbulence background level introduced from disturbances upstream. It is difficult to make any type of accurate inference about the cause of this flow variability without accurate knowledge of local bathymetry, e.g., 2 degree slopes are found to be important, and without adequate spatial resolution of the flow. Hence, in addition to sampling over the vertical, it is also essential to make simultaneous velocity measurements at different locations in the streamwise direction.

A series of experiments off the south coast of Martha's Vineyard will begin in the early spring, and will be designed to measure coastal flows in a wave-dominated environment. The ACM system described above will be used. These measurements will be compared with background measurements under conditions of negligible waves on coastal currents through these experiments. In addition, detailed experiments using both the ACM and LDV systems together will be used to study the near bottom interaction between the wave and current flows (critical to sediment transport). Accurate measurements of boundary geometry will be made during these experiments using an acoustic profiling technique. An estimate will also be made of bed load transport and suspended sediment concentrations.

Through experiments of the type described above, we hope to be able to improve our knowledge of coastal flows so that accurate modeling of sediment transport can be accomplished in the future. It is desirable to put our detailed small scale measurements in the context of larger scale oceanographic studies of the type described by Bob Beardsley and Dave Aubrey, and to contribute to modeling efforts of the MIT group under Ole Madsen. To this end, we try to coordinate our research efforts wherever possible.

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THE APPLICATION AND EFFECTIVENESS OF THE PERCHED BEACH EROSION CONTROL TECHNIQUE AND THE NANTUCKET SHORELINE SURVEY

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PERCHED BEACH

Much of the Massachusetts shoreline is plagued by continual and costly wave, wind, and current induced erosion. Where this erosion threatens shorefront homes and other developments, there is a great demand for new low-cost shoreline protection techniques, because more traditional erosion control methods frequently cost too much. The Shoreline Erosion Advisory Panel (SEAP), organized to demonstrate the effectiveness of various low-cost techniques nationwide, determined as a target definition that structures designed for "inland and sheltered waters" should cost less than $125/foot if installed by a contractor (Caldwell 1977). The critical point is that these structures are designed for shorelines which because of fetch or depth limitations are subject to mild wave climates (wave heights less than 6 feet). Unfortunately, in many cases desperate property oweners embraced these encouraging alternatives and installed structures not designed for their coastal environment.

A low cost erosion technique which creates a widened and heightened beach profile through sand accumulation seaward and landward of a beach parallel oriented "sill" (figure 1) has proven effective in the Chesapeake Bay. Manufacturers of concrete and fabric sills claim onshore sediment transport is the source for sand accumulation to justify their assertion that large perched beach projects do not cause detrimental effects. A perched beach demonstration and monitoring project was initiated to determine the effectiveness of the technique in the more rigourous environment of Massachusetts coastal waters and to identify the sources for the sand accumulation.

Fabric sills (large nylon bags filled with sand) were installed at five locations (figure 2) along Nantucket Sound, Cape Cod Bay, and Pleasant Bay which reflect varying tide and wave climates. Monthly and poststorm beach profiles were run at each site to determine quantitatively changes in beach profile, updrift, downdrift, and within the perch. The relative importance of littoral drift, onshore sediment transport, and bank erosion as sources for the perch was investigated using fluorescent tracers.

The sand bags were stable at all sites even during breaking waves greater than two meters, and durable enough to withstand three months of ice cover without damage. Beach profiles indicate that a typical perch operates on an erosion-accretion cycle coincident with seasonal wave climate cycles. Although a significant perch can develop during the spring and summer accretion period, the first long duration storm or repeated storms with no intervening period of accretion (both of which occur frequently in Massachusetts) completely erode the perch, leaving the bank with no protection for the rest of the storm season (figure 3). The most widely used bags (dimensions 1.5m x 3m x .5m) provided very little bank protection at all sites although they were somewhat effective for widening the summer recreational beach (relative to updrift and downdrift profile) at sites with a low tide range (less than 5m). Tracer studies and beach profiles indicate that alongshore, offshore, and onshore sediment transport all function as the sources for sediment accumulation with the latter being the least important. Therefore, it seems clear that large perched beach projects will cause effects similar to, though less pronounced than, downdrift effects of groins. The relative importance of each mechanism and, in fact, the effectiveness of the technique, depends on the oceanographic conditions at each specific site.

A publication detailing the results of this study will appear in Coastal Structures '79.

NANTUCKET SHORELINE SURVEY

The Nantucket Shoreline Survey is a three part study designed to quantify past and present changes in shoreline location and publish this data in a format comprehensible by potential coastal property owners, and local planners primarily to allow these groups to properly manage the coastline of Nantucket and avoid the inherent risks of construction in erosion prone areas. This study, being in part run at the local level, will also be an educational project encouraging the participation of Nantucket residents in the data gathering, reduction, and presentation phases of the study. By encouraging this development of a better understanding of coastal processes and shoreline changes among Nantucket residents, it is expected that this study will encourage a more enlightened approach to managing the fragile coastline.

PHOTOGRAMETRIC SURVEY

Mike Goetz, now working for the New England River Basins Commission, has completed a photogrametric survey of shoreline changes on Nantucket under the supervision of Dr. J. Fisher at U.R.I. Mike's work will be combined with the other two parts of this study for a comprehensive examination of shoreline changes on Nantucket.

HYDROGRAPHIC SURVEY

The Beach Erosion Board published four sheets for the south shore of Nantucket which plot on each sheet the MHW shorelines in 1846, 1887, and 1955. The shoreline changes will be measured at 1000 foot intervals and compared with the photogrametric information.

FIELD BEACH PROFILING

The final part of this project will be a beach profiling program to actually measure progressive changes in beach profiles at 20-30 locations around the island representing critical erosion areas and areas of particular environmental or management concern. Some of these profiles will be relocating original profiles by Marindin in 1891.

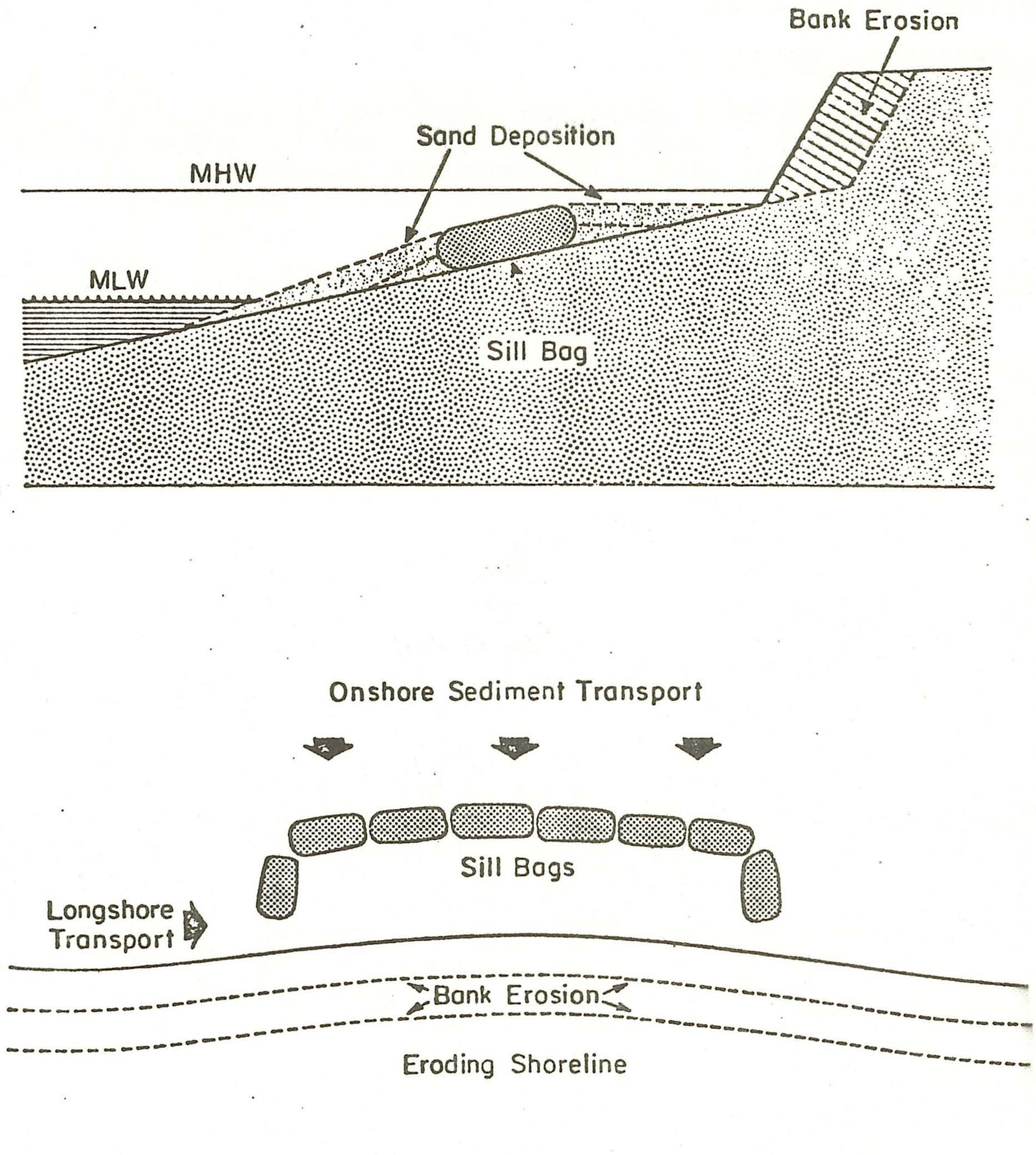


Figure 1. Schematic Section (top) and plan (bottom) view of a sill bag perched beach.

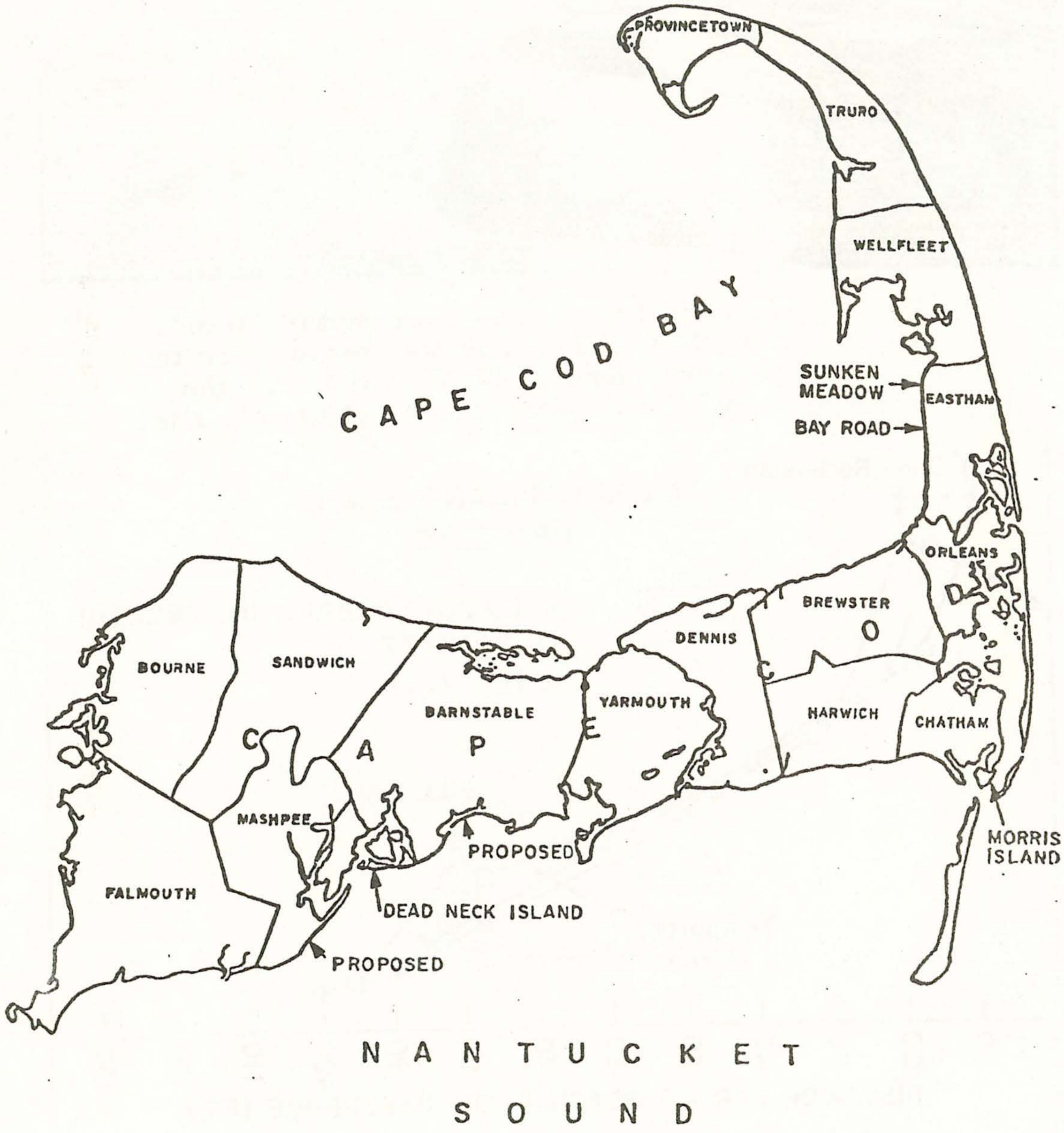
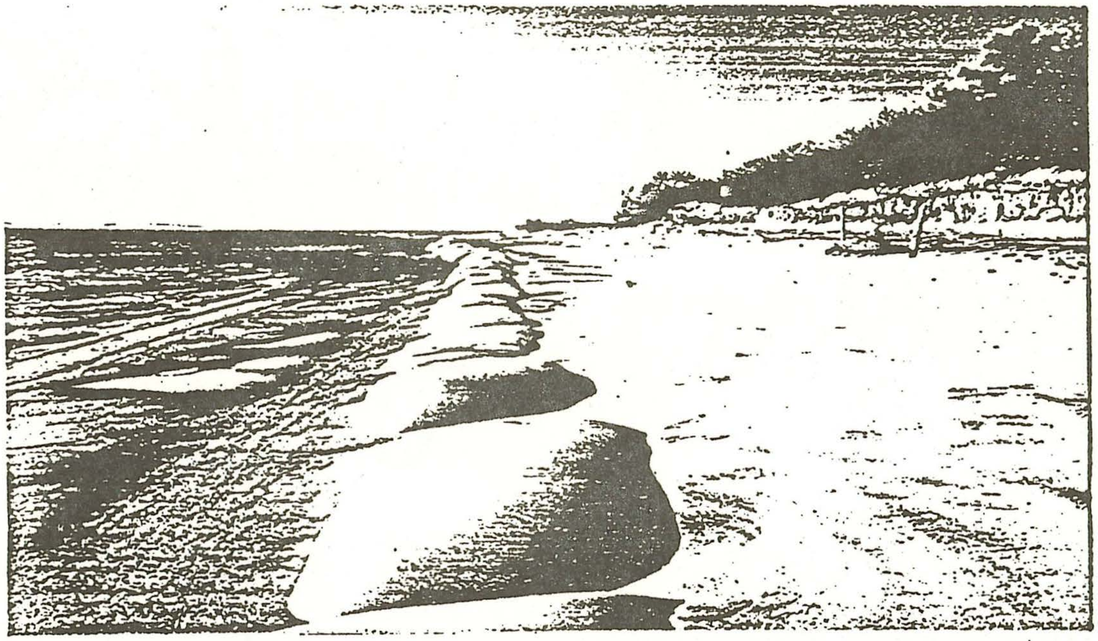


Figure 2. Map of Cape Cod showing location of existing and proposed sill bag perched beach projects.



Perched beach project at Morris Island, MA. This photograph was taken after the January storm (1/12/78) which was the only time a perch developed at this site.

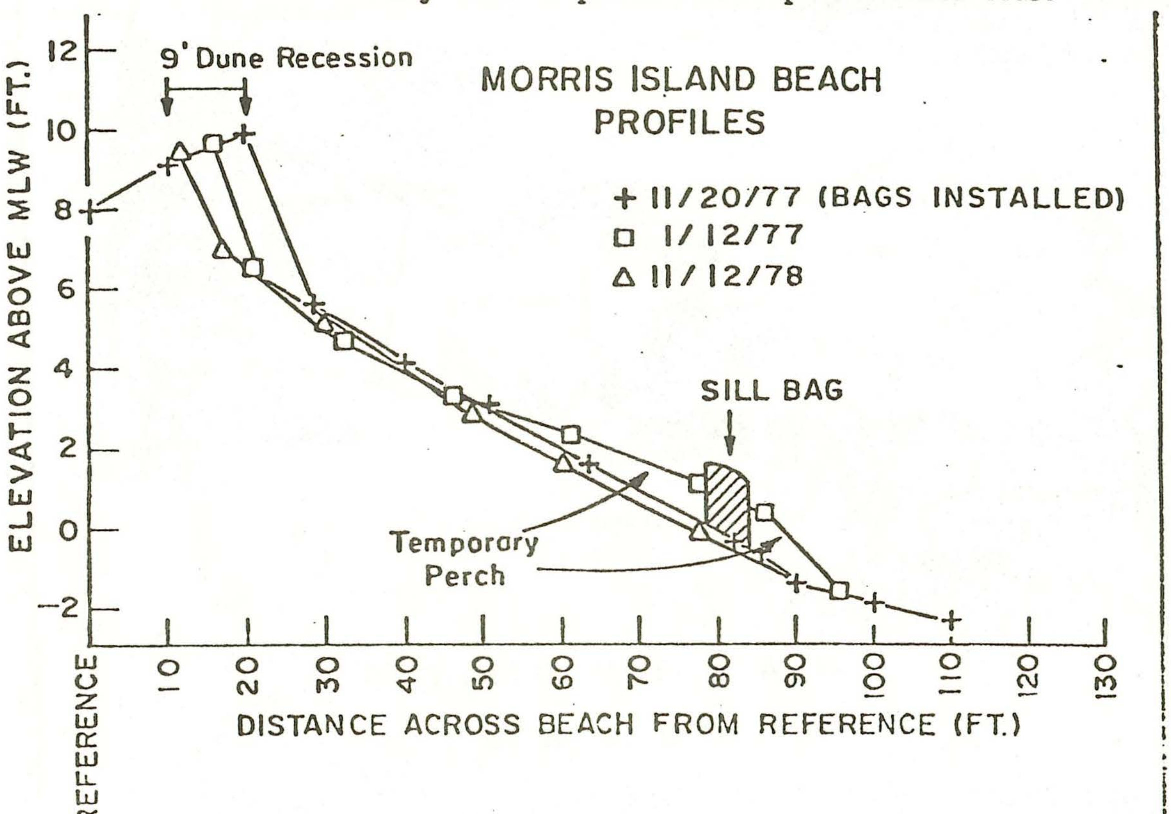


Figure 3. Comparison of beach profiles at Morris Island. This profile runs perpendicular to the beach across the second bag from the bottom

THE HYDROLOGY OF COASTAL SALT MARSHES

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Coastal salt marsh systems develop in relatively sheltered, low-energy environments, and water flow serves not only to transport sediment and detritus but also to move the soluble inorganic nutrients on which growth of the marsh plants and consequent deposition of peat is dependent. This research effort is aimed at understanding surface flow, subsurface flow, and the boundary condition between these two regimes; namely, infiltration/exfiltration across the peat-water interface. Initial measurement efforts have concentrated on the latter process.

An infiltrometer has been constructed to measure infiltration and exfiltration on the intertidal marsh. This device consists of a cylinder of approximately ¼ m^2 cross-sectional area, which is stood upright on the marsh and driven 10 cm into the sediment. A differential level sensor is used to operate a metering pump, which maintains internal water level equal to the external level during tidal inundation of the marsh. Metering pump volume is compared against water storage in the cylinder, as measured by a stage recorder, to obtain infiltration. In the Great Sippewissett Marsh, typical infiltration is of the order of 3 cm per tidal cycle near the tidal creeks, and drops to 1 cm or less per cycle at some locations further from the creek. Most of the water which infiltrates during flood tide is observed to exfiltrate during ebb. A refined infiltrometer, presently under construction, should be able to accurately measure the difference between infiltration and exfiltration, and will also be employed in direct measurement of chemical fluxes across the peat surface.

Other aspects of this research will include the systematic evaluation of the hydraulic properties of salt marsh peats and the influence of salt marsh vegetation on surface flow. It is expected that remote sensing data will prove helpful in these tasks, should significant relationships between vegetation and flow properties be shown. Extensive measurement of piezometric head in the subsurface, and perhaps the surface flow regime, will be accomplished with an acoustic piezometer network which is also being developed as part of this research program.

MASSACHUSETTS' COASTAL WETLAND RESTRICTION ACT FROM A MANAGERIAL PERSPECTIVE

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ABSTRACT

Implementation of the Coastal Wetland Restriction Act, Chapter 130, Section 105 of the Massachusetts' General Laws is a mandated responsibility of the Department of Environmental Management. The purpose of the act is to promote public safety, health, and welfare and to protect public and private property, wildlife and marine fisheries by restricting human alterations in certain coastal wetlands. Orders are adopted which place land use restrictions on the individual property owner's deed. The coastal wetland types subject to the act include ecologically significant barrier beaches, dunes, salt marshes, land containing shellfish, and salt ponds.

The department makes the assumption that most all coastal wetlands are significant and should be restricted. However, in order to avoid unduly encumbering private property, only those wetlands or portions of a wetland which meet the following general criteria will be restricted:

1) The wetland must function as described in Sections 27-29 and 32-34 Part II of the Regulations Under The Wetland Protection Act General Laws Chapter 131, Section 40; and,

2) There must be a high probability that certain alterations of the wetland will be detrimental to the function.

Documentation of existing data and pertinent information concerning the wetlands is necessary to justify a restriction and serves as a means of coordinating research endeavors and management needs. While management decisions often seem hasty and subjective, there is often a lack of willingness on the part of the researcher to understand the management process. In view of the fact that there is a large number of reputable research institutions in Massachusetts, the future is favorable for solving environmental problems in a state having a notably complex and dynamic coastline.

INTRODUCTION

In order to understand the Commonwealth's perception of wetland values, some knowledge of existing wetland legislation in Massachusetts is essential. In general, there is one Wetlands Protection Law; however, it has been subdivided into three acts for the purpose of reflecting administrative and substantive differences. Each law, the date the law was effective, and the Department administering the law are listed below:

1) M.G.L.A. Chapter 130, Section 105 (Coastal Wetland Restriction Act), Feb. 1966, Environmental Management;

2) M.G.L.A. Chapter 131, Section 40 (Wetland Protection Act), Dec. 1967, Environmental Quality Engineering; and,

3) M.G.L.A. Chapter 131, Section 40A (Inland Wetland Restriction Act), Sept. 1968, Environmental Management.

The scope of this paper is limited to a discussion about the Coastal Wetland Restriction Act, its interpretation, and a general perspective concerning the restriction program. Specifically, the act states:

> The Commissioner, with the approval of the board of environmental management may from time to time, for the purpose of promoting the public safety, health, and welfare, and protecting public and private property, wildlife and marine fisheries, adopt, modify, or repeal orders regulating, restricting or prohibiting dredging, filling, removing, or otherwise altering, or polluting coastal wetlands.

Recognizing the broad and general nature of this language, the managing administration has the duty of defining the purpose in more specific terms, formulating a systematic means of identifying the appropriate wetlands, and establishing a defensible policy which protects both the environment and private property rights. Socioeconomic, political, legal, and scientific issues are interrelated to a great extent in the process of developing a realistic management policy. However, science is the fundamental discipline required for understanding an environment as dynamic as the coastal zone.

INTERPRETATION OF THE ACT

The Coastal Wetland Restriction Act provides for the protection of certain wetlands by limiting human alterations. These limitations are set forth in a straight forward manner. A restriction order is adopted and recorded on the individual property owners deed, thereby affecting any present and future owners. The order primarily consists of a list of allowed and prohibited activities which, in effect, excludes the construction of habitable structures. Part of the existing order states:

> No person shall perform any act or use in said wetland in a manner which would destroy the natural vegetation of the coastal wetland, substantially alter existing patterns of tidal flow, obstruct the movement of sediment or alter the natural contour of the coastal wetlands.

The term 'coastal wetland' means barrier beaches, beaches, dunes, land containing shellfish, salt ponds, or salt marshes. All restricted coastal wetlands must be ecologically significant in order to be consistent with Massachusetts' Coastal Zone Management policy. However, determining ecological significance of coastal wetlands with the use of rating systems may not provide a reliable tool for management. Rating of salt marshes, for example, has been shown to be unreliable (Oviatt et al. 1977). The determination that a wetland is a "significant" coastal resource is never clear-cut; instead, it lends itself to interpretations and opinions that can be defensibly rendered only by professionals in relevant fields. The best management strategy is one that is based on understanding nature's systems and optimizing their functions (Clark, 1977).

GENERAL MANAGEMENT POLICY

The Wetland Restriction Program assumes most all coastal wetlands are significant. The state-of-the-art in coastal zone research enables the understanding of numerous resource functions, so that management decisions can be made without requiring site specific research. Of course, decisions are far more accurate and meaningful if they are based on site specific data, but policy should not require it.

Despite the fact that most wetlands are significant and should be restricted, private property rights and existing land use patterns must be respected. This is particularly true in Massachusetts where home rule is so important and private property rights exist seaward to mean low water. Protection of the law itself is maintained through the proper consideration of existing and, to a certain degree, intended use of the land.

In order to avoid unduly encumbering private property, general criteria have been adopted to enable the determination of which wetlands or portions of a wetland will be restricted. First, a wetland must function as described in Part II of the

Regulations Under the Wetland Protection Act General Laws Chapter 131, Section 40. A number of coastal wetlands are addressed in this document, but for the purposes of Wetland Restriction, Sections 27-29 and 32-34 describe the six wetland types listed previously. Considering each interest of the Restriction Act and assuming the wetland functions as described, the manner in which these functions serve the statutory interests can be listed as follows:

Public safety-storm damage prevention and flood control;
Public health-water quality and supply;
Public welfare-food supply, research areas and aesthetic value;
Public and private property-sediment supply and ecological productivity;
Marine fisheries-nursery and habitat value and food source potential; and
Wildlife-breeding, nesting, and feeding grounds.

Secondly, there must be a high probability that certain alterations will be detrimental to the natural function of the wetland and the manner in which the function serves the statutory interests. These certain alterations will be the prohibited activities listed in the order. The allowed activities listed in the order will be regulated by authority of the Town Conservation Commission and Department of Environmental Quality Engineering pursuant to the Wetland Protection Act. Since the activities prohibited in a restricted wetland could be regulated if the wetland were unrestricted, a systematic and consistent means of wetland identification, verification, and documentation is required to justify the restrictive nature of the order.

INTERACTION BETWEEN RESEARCH AND MANAGEMENT

Documentation of scientific data, both general and specific in nature, is the single most important aspect of the restriction program. Since the department does not presently function as a research organization, decisions must initially be made using existing data and later supported by results of future research. A knowledge of on-going research, updated list of publications, and research investigators is necessary for the manager. Communication and interaction between the research and management fields is a simple means of accomplishing the common goal of both - that is, environmental protection. For example, the program has initiated a beach profile network for the state. With additional knowledge of other existing profile sites, a co-operative research effort could be established and prove to be beneficial in a number of ways. Communication could be defined by the researcher's availability for courtroom testimony and desire to serve as a consultant for local governments. Needless to say, there are many possible avenues for the manager to express his scientific needs and for the researcher to contribute to environmental policy.

Policy and decision making for a program like wetland restrictions requires the input from a number of professionals in diverse fields. Without this input, decisions can be made subjectively. Other problems are related to making hasty decisions, such as, deadlines and legal and political restraints; but, these have less to do with the substantive issue of scientific documentation. The burden of responsibility to obtain information lies with management. On the other side of the coin, information may be hard to obtain if researchers are unwilling to understand or participate in the management process. And in Massachusetts, where there is a large number of reputable research institutions, this could be detrimental. Since the state's coastline is extremely dynamic and many problems are associated with its complexity, a 1Onscious effort to interact between many disciplines is needed to properly protect the coastal environment.

SUMMARY

As a means of protecting coastal wetlands in Massachusetts, there is a state law which allows for the restriction of certain land uses, commonly referred to as the Coastal Wetland Restriction Act. Due to the restrictive burden that is placed on the individual property owner, careful consideration of the wetland function and the documentation of relevant data must serve to justify all wetland restrictions.

The general criteria used in determining which wetlands or portions of a wetland (i.e. barrier beaches, beaches, dunes, salt marshes, salt ponds, and land containing shellfish) can be restricted include the following:

1) The wetland must function as described in <u>Regulations Under the Wetland Protection Act General Laws Chapter 131, Section 40; and,</u>

2) That certain alterations of the wetland will be detrimental to the function.

Existing data, relevant information, and results from future research are incorporated into the selection and justification of restricted wetlands. Therefore, the fields of management and research need to coordinate their separate interests in order to solve the diverse problems which face the Massachusetts coastal environment.

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Clark, John, 1977. Coastal Ecosystem Management: John Wiley and Sons, Inc., New York, 928 pp.

Oviatt, C.A., Nixon, S.W., and Garber, J., 1977. Variation and Evaluation of Coastal Salt Marshes, Environmental Management, 1(3):201-211.

Regulations Under the Wetland Protection Act General Laws Chapter 131, Section 40; Regulations for Wetlands, 12 Code of Massachusetts Regulation 310.

GEOMORPHOLOGY OF THE BOSTON HARBOR ISLANDS

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The Boston Harbor shoreline is unique to the coastal United States. This coastal environment largely consists of drumlin and rock core islands, complex spit-tombolo systems, drowned estuaries and drumlin headlands.

Because many of the geomorphic structures found within the Boston Harbor area are of glacial origin, much of the Harbor's gross shoreline configuration can be attributed to the results of the Pleistocene Epoch. Many of these Harbor Islands and drumlin headlands are aligned with the direction of Pleistocene ice flow, and Kaye (1961, p. 74) has discovered the resultant stratigraphy of the adjacent Boston area to consist of four glacial drifts interbedded by three layers of marine clays. This appears to indicate at least four major ice advances followed by four ice retreats.

These advance-retreat cycles may indicate why some of the drumlins are not in alignment with the direction of ice flow. Kaye (1961) has also found many pebbles within the Boston inland drumlins oriented at S70E. The till boulder fabric in these features is well sorted with very few clasts exceeding ten feet in diameter. Upson and Spencer (1964, p. 21) further indicate that all of the unconsolidated sediment found within these drumlin features is of glacial origin.

This unconsolidated drumlin till is the source of beach sediment for much of this coastal system; however, some of theHarbor Island beaches do not display this easily eroded till-fabric beach matrix, but rather shingle and cold water carbonate beaches have developed independently as well as in association with the detrital quartz island beaches. This variation of beach fabric in conjunction with energy differences appears to indicate a multi-beach formation hypothesis for this coastal system.

The relationship between spit formation and long term coastal processes has been recognized as an important mechanism in shoreline development. However, recent investigations have indicated that short term-high energy events are a major factor in the lateral and vertical development of spits. Sediment analysis and aerial photograph interpretation of spits in the Harbor Island system demonstrate that storm conditions are also a control of development and subsequent dune build-up.

The accretion of a spit on Thompson's Island in Boston Harbor, Massachusetts, is attributed to both longshore transport of eroded glacial sediments and washover materials resulting from storm events. Bedding within the spit appears to be cyclic: coarser ($M_z = -3\phi$), finer ($M = 0\phi$). The general composition of this spit sediment is quartz sand, carbonate shell and argillite shingle. The deposition of the argillite material is interpreted to represent a discontinous high energy lag and is found exposed on the surface of the forebeach and in buried layers within the incipient dune ridges. Aerial photographs and sediment tracer studies indicate that movement of the beach material is from two general directions; northeast to southwest and southeast to southwest. These quadrants represent the origin of dominant storm activity.

A cuspate foreland mapped on the southeast end of Grape Island is unique because it is the only foreland feature in the Boston Harbor Island system to contain relict beach/berm ridges. This foreland was deposited against a glacial till upland surface formed on the drumlin which makes up Grape Island.

During its initial stage, as the drumlin was submerged by rising sea level, wave action eroded a low cliffed shoreline. After submergence, with the drumlin now an island, wave erosion along the northeast shoreline (with maximum fetch being two miles to the north across Hull Bay) supplied sediment to longshore transport process moving southward. A spit ridge was then built along the entire length of the foreland and enclosing a lagoon. This spit ridge is present as the first of a series of relict beach/berm ridges.

Subsurface sediment obtained from coring the swales (lagoons) and beach ridges indicate alternating deposits of shingle in the ridge and very fine sand, silts and clays in the swales. These deposits relate to the relative rates of energy during the development of the cuspate foreland. Computer mapping of the height to width ratio of pebbles in the core samples supports the concept that the ridges were formed by coastal processes similar to today.

REFERENCES

Kaye, C.A., 1961. Pleistocene stratigraphy of Boston, Massachusetts. U.S. Geol. Survey Prof. Paper 424-B, p. 73-76.

EFFECTS OF OVERWASH PROCESSES AND OFF-ROAD VEHICLES ON NAUSET SPIT, CAPE COD, MASSACHUSETTS

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Nauset Spit is an eroding barrier along the outer Cape Cod shoreline. While the majority of the beach is backed by a well-developed barrier dune system, there are breaks in the dune line which permit overwash during storm conditions. These breakthroughs range from small dune gaps to large, barren flats, such as those created by the February 6-7, 1978 northeaster at Coast Guard Beach.

Off-road vehicles can cause substantial impact on a barrier beach system. Drivers utilize existing beaches in the dune line as passageways between the beach and sand roads in the barrier flats, thereby preventing revegetation. Also, vehicular passage across the dunes can quickly result in devegetation and blowouts. These artificially-created pathways can serve as overwash channels during storm conditions. It is possible that frequent overwashes are not the normal course of events, and the present condition reflects, at least in part, the heavy usage of this spit by ORVs. A continuing NPS study of Nauset Spit is aimed at evaluating trhe relative roles of overwash and dune building in order to determine the impact of vehicles on these processes.

During an overwash event, an electromagnetic current meter and flow depth indicator are used to record the overwash hydraulics data. From these measurements, coupled with field surveys bracketing the storm events, it will be possible to determine the nature of this sediment transport process. Water discharge values can also be calculated from the velocity and flow depth records. In this manner it will be possible to indicate the potential for marsh-bay flushing and flooding based on the volume of water flowing across the barrier via washover fans.

Foredune ecology research is also an important part of this overall study. Plant communities associated with the following shore conditions are being studied by using standard botanical techniques: (1) washovers on barrier flats, (2) washovers closed with beachgrass, (3) washovers on salt marshes, (4) incipient washovers, and (5) stable foredunes. The data is collected in selected areas as a belt traversing the barrier from ocean to bay. Cover and frequency values are obtained directly from the quadrant data. More sophisticated statistical analyses are also being conducted to permit quantitative comparisons and categorization of these different types of environments.

A NANTUCKET SHOALS HYDROGRAPHY STUDY

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A series of hydrographic surveys was begun with Sea Grant support in May, 1978, in the Nantucket Shoals region of the New England continental shelf. The principle objectives of the cruises were: (a) to begin a synoptic hydrographic program to measure and document the spatial and temporal structure and variability of the water properties in the Nantucket Shoals/Great South Channel region over one annual cycle; (b) to conduct a pilot moored current meter array experiment to obtain direct measurements of wind-driven and other subtidal transient currents; and (c) to begin to synthesize the new hydrographic and current data into an improved circulation scheme for Nantucket Shoals. A total of six hydrographic cruises is planned and three have been completed at approximate intervals of one cruise every two months. The first hydrographic survey, cruise NS1, was conducted May 28 - June 2, 1978; the second survey, cruise NS2, on July 15-20, 1978; and the third survey, cruise NS3, on September 14-19, 1978. All three cruises were completed on the R/V EDGERTON from MIT. CTD stations were taken approximately every five nautical miles offshore, and in the general area to the east and south of Cape Cod, Nantucket, and Martha's Vineyard. The general cruise track for all three hydrographic surveys and regional topography can be seen in Figure 1 with station locations indicated by dots.

The surface temperature maps from the first three surveys show localized upwelling occurring over the eastern shoals due east and southeast of Nantucket Island. We believe this is caused by a combination of tidal mixing and mean flow characteristics rather than by a transient wind forcing. If this hypothesis is correct, then localized upwelling should be observed year around in the hydrographic data. The surface salinity map shown in Figure 2 indicates the upwelled water to be more saline than the water above the shoals, and similar in T/S properties to water in the lower seasonal thermocline in the Gulf of Maine to the east. Vigorous tidal mixing in the shallow water above the shoals is another process which modifies the water characteristics. The vertical sigma-t difference between the surface and bottom is contoured in Figure 3 to show the transition between the stratified and vertically homogeneous water. Seasonal heating and cooling, wind mixing, tidal mixing, and upwelling can all modify water properties. We hope to understand the roles of these processes by tracing the distinct T/S characteristics of the different water masses near Nantucket Shoals.

Future work involves a continuation of the hydrographic cruises to complete the annual cycle and deployment of a pilot moored current meter array in January-February, 1979. We hope to use knowledge of the observed regional hydrography and data from the pilot current meter array to deduce a better regional circulation picture. Looking further forward in time, we hope to obtain Sea Grant support for a substantial moored array program to make direct measurement of the regional currents.

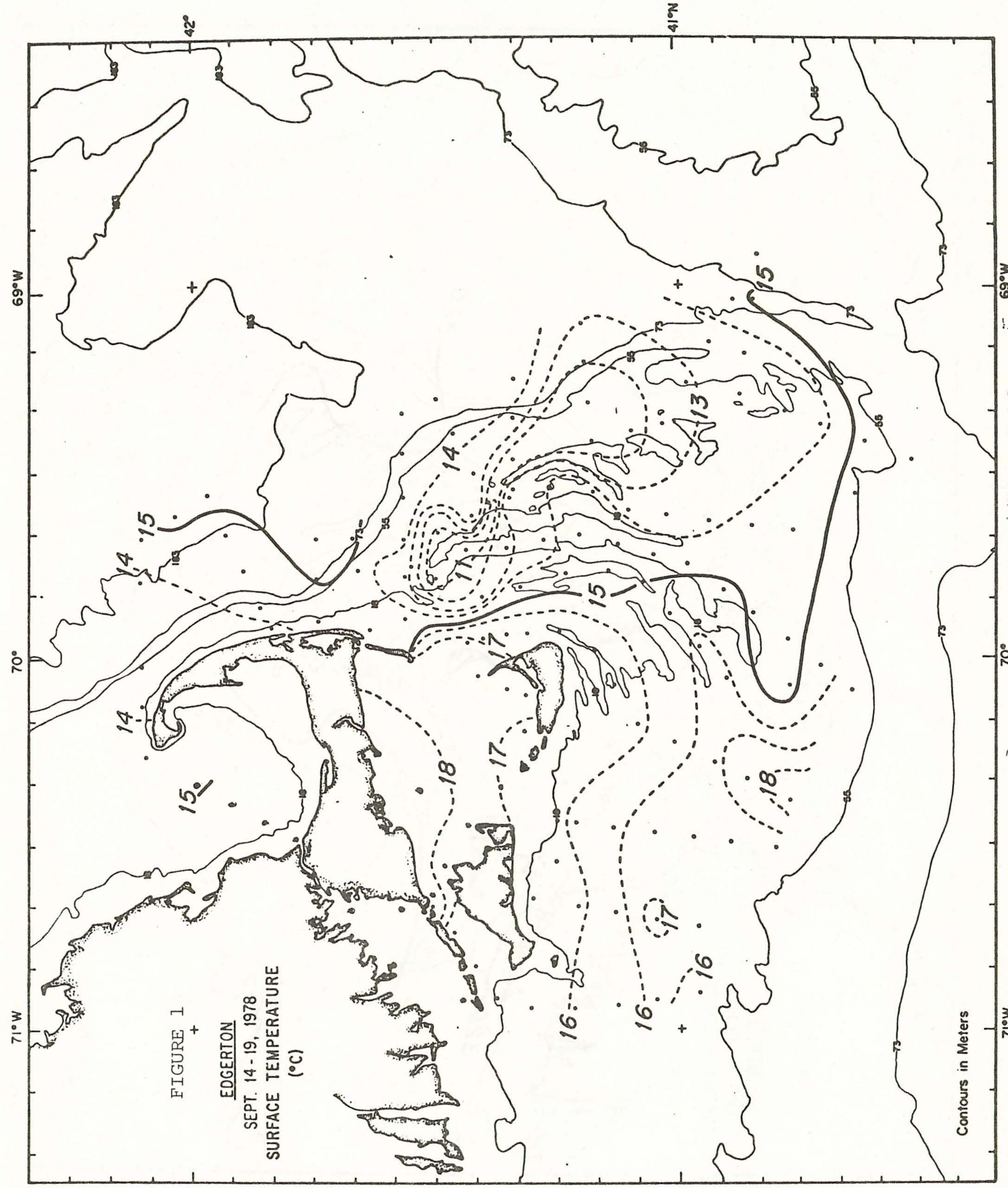

FIGURE 1

EDGERTON

SEPT. 14-19, 1978

SURFACE TEMPERATURE

(°C)

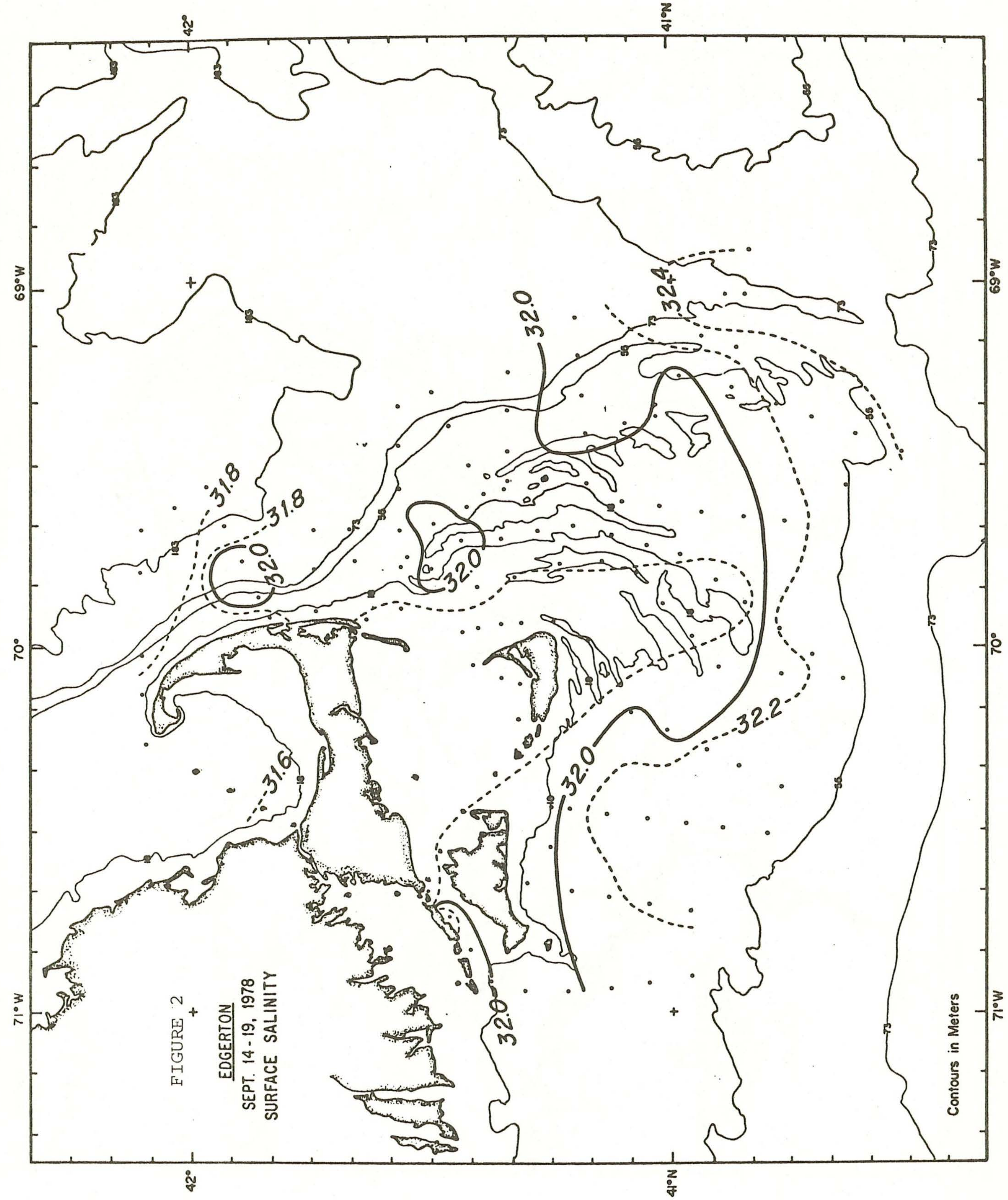

FIGURE 2
EDGERTON
SEPT. 14-19, 1978
SURFACE SALINITY

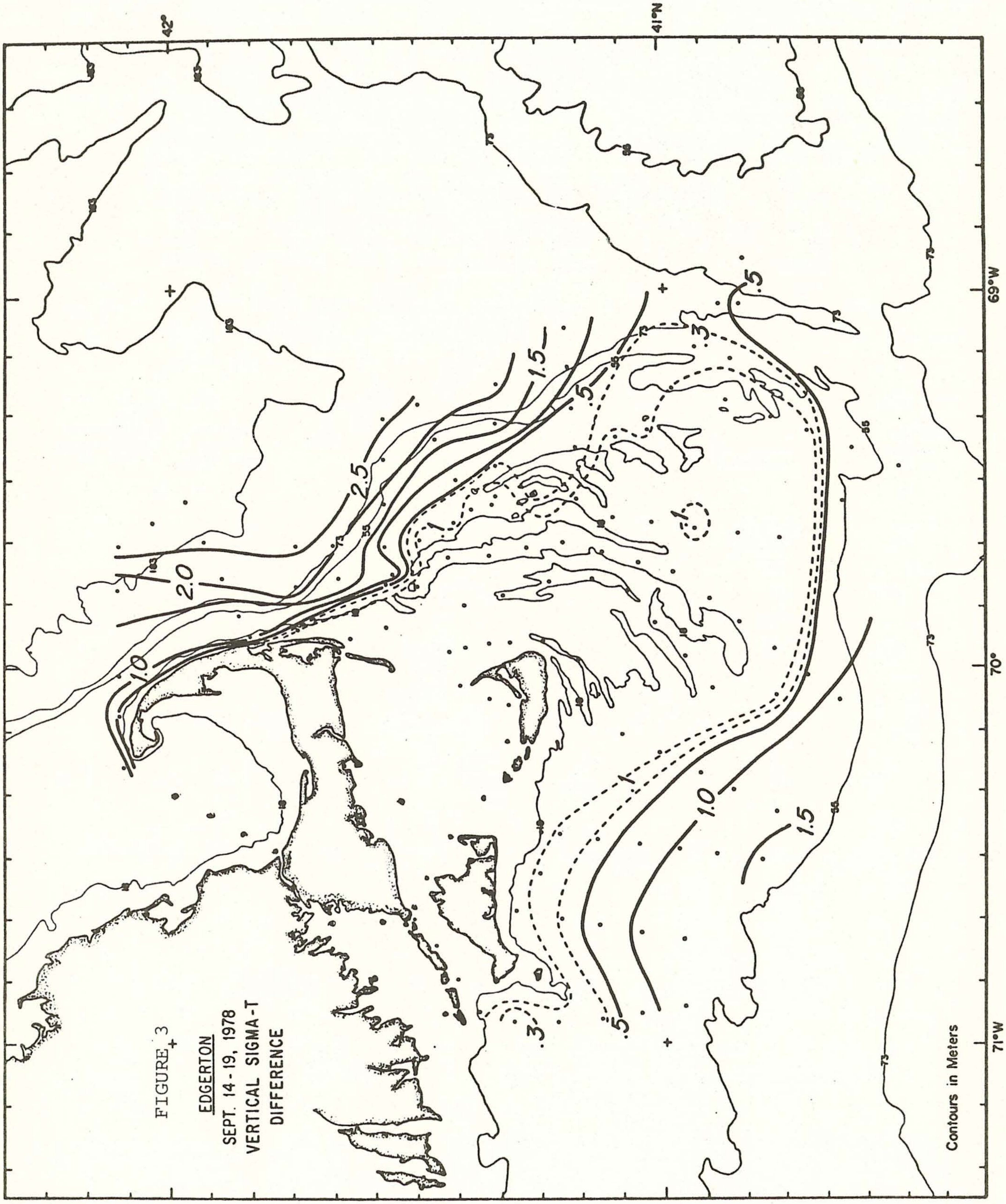

FIGURE 3
EDGERTON
SEPT. 14-19, 1978
VERTICAL SIGMA-T
DIFFERENCE

SURF ZONE PROCESSES - WHAT WE DO AND DON'T KNOW, WITH SPECIAL REFERENCE TO LONGSHORE SEDIMENT TRANSPORT

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Synopsis by D.G. Aubrey
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This keynote address emphasized the deficiencies in our knowledge of surf zone processes. Much of the discussion centered on a recent review paper by Greer and Madsen (1978) on the current state of knowledge of longshore sediment transport. In particular, he analyzed the sparse data set upon which the currently-used formulae for longshore sediment transport are based.

REFERENCE

Greer, M.N. and O.S. Madsen, "Longshore sediment transport data: a review", submitted to the Proceedings of the 16th Conf. on Coastal Engineering, Amer. Soc. of Civil Eng., 1978.

SOURCE AND FATE OF URBAN ESTUARINE SEDIMENTS

BOSTON HARBOR

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The urban estuary is a fragile resource subjected to a variety of human pressures in which the sedimentary regime both influences and records the environmental response to these pressures. Understanding estuarine sedimentary processes, therefore, is necessary for wise coastal management.

Boston Harbor is an ideal urban estuary for study in that most river flow has been stopped by dams and urban development: dominant freshwater and sediment input is from two sewer outfalls (that serve the greater Boston area) near the mouth of the harbor. Water column sampling plus preliminary current measurements made during a continuing Sea Grant-sponsored program suggest that a considerable portion of the outfall material moves directly or indirectly into the harbor. As a result, parts of the harbor bottom are covered with organic-rich (3-5% organic C) polluted sediment (Fig. 1). Cores in these sediments show a major increase in pollutant influx (including trace metals such as Cd, Pb, Ni, and Cu) and sedimentation rates of 0.5 cm/yr during the past 80 years (when outfalls have grown in size and use).

To document the movement of these anthropogenic contaminants, suspended matter and water column measurements have delineated spatial, tidal, diurnal and seasonal variations within the system, as well as outline the imprint of sewage upon the estuarine regime. Particulate concentrations within the harbor range from 0.5 to 10 mg/l, with tidal variations often rivaling seasonal changes. Particulates come from three main sources: sewage outfalls proper, biologic production, and resuspension of bottom sediment (often modified material from the other two sources). Laboratory and scanning electron microscope analyses show that many particulates are totally or partly anthropogenic, and suggest the influence of organics in the transport of heavy metals. The importance of resuspension is not fully understood, but preliminary sediment trap experiments indicate considerable bottom sediment resuspension in the outer harbor waters. The nature of suspended particles also can be understood by documenting the dissolved nutrient content within the water mass in which they occur. For example, outfall waters tend to contain high levels of nutrients, while biologically-produced material is associated with relatively low nutrient concentrations.

Future research is aimed at better defining the current regime within the harbor so that movement of material can be predicted. These data should help public officials in planning future placement of sewer outfalls and storm drain overflows within the harbor area.

FIGURE CAPTION

Figure 1. Sub-bottom echo-sounding profile in Boston Harbor, showing the configuration of the bottom (B) below the water surface (S) Acoustic bottom (AB) is assumed to be Paleozoic basement. The intervening layers between B and AB are sedimentary strata that are well-defined, except in areas where highly organic (polluted) sediments mask the returns, seen here in the central portion of the figure. Vertical scale of the figure is 1/16 second or 93m. Horizontal distance shown in this figure is approximately 1 km.

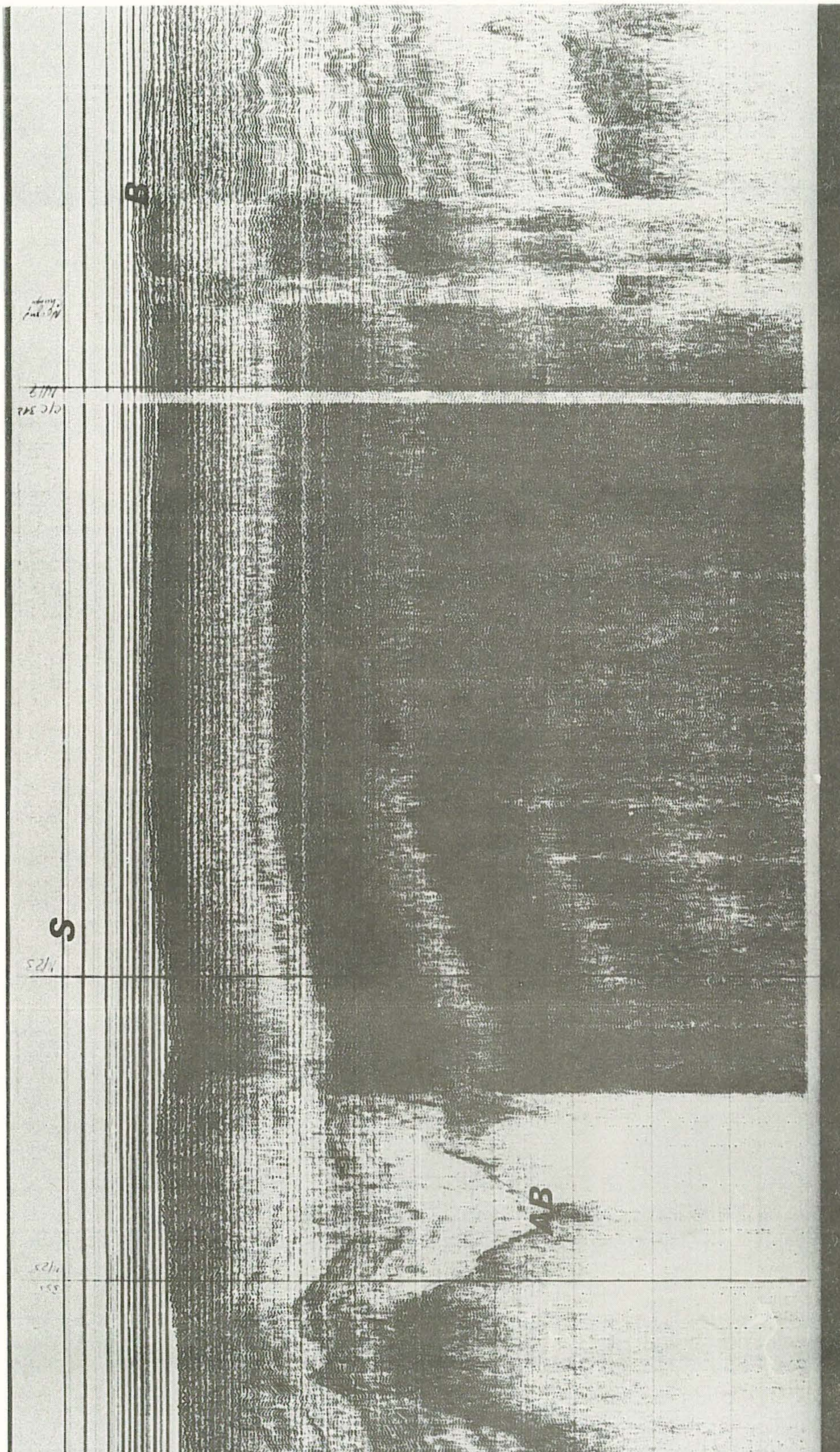

Figure 1.

UNITED STATES GEOLOGICAL SURVEY

RESEARCH IN THE MASSACHUSETTS COASTAL ZONE

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INTRODUCTION

The United States Geological Survey (U.S.G.S.) in cooperation with the Massachusetts Department of Public Works (D.P.W.) is conducting marine geologic studies in the waters adjacent to the State of Massachusetts (fig. 1). Major objectives of the marine cooperative include an assessment of the offshore mineral resources principally sand and gravel, evaluation of the environmental impact of offshore mining of mineral deposits and offshore disposal of solid waste material, identification and mapping of the offshore geology and shallow structure, and determination of the geologic history of the region. Field studies consist mostly of closely spaced high-resolution seismic reflection profiling and vibracoring. Presently, more than 3000 km of seismic profiles and 100 vibracores (fig. 2) have been obtained from Cape Cod Bay, Buzzards Bay, Vineyard Sound, eastern Rhode Island Sound, and Nantucket Sound.

Geologic maps have been published for Cape Cod Bay (Oldale and O'Hara, 1975a) and Buzzards Bay (Robb and Oldale, 1977). Other publications resultant from the marine project are listed at the end of the paper.

METHODS

Seismic-reflection profiling: The high-resolution seismic profiling system used most often in the marine program consists of an EG&G Uniboom[1] sound source and hydrophone array. This system is capable of resolving subbottom reflectors as thin as 1 m and provides sediment penetration to depths of 75 to 100 m below the sea floor which generally includes the entire unconsolidated sedimentary section underlying the inner shelf of Massachusetts. Where the unconsolidated section is thicker,

[1]Trade names in the publication are used for descriptive purposes only, and do not constitute endorsement by the U.S. Geological Survey.

more powerful, deeper penetration systems are used. Navigational control is provided by Loran C and seismic profile track lines are generally spaced less than 2 km apart.

Vibracoring: As a result of glacial, fluvial and marine erosion of the inner shelf of Massachusetts, sedimentary deposits originally deeply buried now outcrop or are found within a few meters of the sea floor in many places. Seismic reflection records are initially studied to locate such sites so that they can be cored and the material identified. Vibracorers ranging from 4.3 to 12.2 m (14 to 40 ft) in length have been used as they allow sampling of coarse sand and gravel and very compact sediments such as glacial tills. In the laboratory, the cores are visually examined to identify lithology and sampled for petrologic, palynologic, and paleontologic studies and radiocarbon dating. The core data in combination with the acoustic units and major unconformities defined by the seismic data allow construction of isopach maps of important geologic units, structure maps of the unconformable surfaces, and geologic maps of the sea floor.

SUMMARY OF SCIENTIFIC RESULTS

The seismic-reflection and vibracore data have provided information on the geologic framework and Cenozoic development of the southeastern Massachusetts inner Continental Shelf. The deepest acoustic reflector represents a regional unconformity of late Tertiary or early Pleistocene age underlain mostly by consolidated rocks of late Precambrian and early Paleozoic age and in part by unconsolidated strata of late Cretaceous to early Pleistocene age. In Cape Cod Bay, the unconformity is locally underlain by strata (fig. 3, unit Tcp) of possible Eocene age that occur as isolated erosional remnants (O'Hara and Oldale, 1976). Beneath much of eastern Rhode Island, Vineyard Sound and Nantucket Sound (O'Hara and others, 1976), this unconformity is underlain by strata (fig. 4, unit Ku) of late Cretaceous and Tertiary (?) age that lie seaward of a deeply eroded cuesta.

Glacial drift of late Wisconsin age blankets the unconformity over most of the inner shelf. Locally, the seismic data show folding and faulting within the offshore parts of the Nantucket and Buzzards Bay moraines in Rhode Island Sound. This deformation is similar to that observed in the Gay Head Cliffs of Martha's Vineyard, and may indicate that the end moraines are in part glaciotectonic features (Oldale and O'Hara, 1978a). Within Cape Cod Bay the upper Wisconsin drift is thought to be mostly of sublacustrine origin, deposited directly by the ice into deep water. Numerous imbricated northward-dipping reflectors are inferred to be basal tills deposited during readvances of the ice front. Off Provincetown, the drift deposits are believed to consist of deep-water glaciolacustrine sediments (fig. 3, unit Ql) and shallow-water foreset and bottomset sediments (fig. 3, unit Qld) of large outwash-plain deltas (O'Hara and Oldale, 1976).

The glacial drift surface off Massachusetts is locally incised by stream valleys. Within Cape Cod Bay, the post-glacial fluvial drainage was northeastward toward the Gulf of Maine (Oldale and O'Hara, 1975b) and in Buzzards Bay, Vineyard Sound and eastern Rhode Island Sound, the drainage was southwestward toward Block Island Sound (O'Hara and others, 1976). The valleys are filled with mostly estuarine sediments (fig. 4, unit Qfe) that were deposited as sea level rose and drowned the pre-existing fluvially modified glacial drift surface. Ten radiocarbon dates on shell and peat cored from these estuarine deposits allowed construction of a local Holocene sea level rise curve for the southeastern Massachusetts offshore area (Oldale and O'Hara, 1978b; 1978c). 10,000 years ago, relative sea level was about 39 m below its present level and the rate of rise was about 1.7 m/100 years. Between 10,000 years and 6,000 years, the rate of rise gradually slowed to about 0.3 m/100 years and remained at this rate until about 2,000 years ago. At that time, the rate of rise dropped to about 0.01 m/100 years.

A ubiquitous, nearly flat-lying reflector caps the glacial drift and estuarine deposits filling the post-glacial valleys and is thought to represent a planar marine unconformity (fig. 3, reflector MU) cut during sea level rise as the surf zone transgressed over the older deposits. Several Holocene marine deposits are found atop this wave cut unconformity. In areas of active tidal currents, sand ridges are common and in areas of lesser tidal flow or deeper water, deposits of silt and clay (figs. 3 and 4, unit Qm) cap the marine unconformity. Adjacent to the coastal beaches, sand deposits are presently forming above the wave cut surface.

CONCLUSION

The U.S.G.S./Mass. D.P.W. marine cooperative has mapped a large part of the Massachusetts coastal zone. Products of the marine program include isopach, structure, and geologic maps useful in the economic evaluation of the State's offshore mineral resources. Most of the data collected during the program are available to other scientific investigators, consultants and engineers. Unfortunately, all the cores that were collected by the marine cooperative were completely destroyed in a warehouse fire early in 1978.

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FIGURE CAPTIONS

Figure 1. Index map of Massachusetts offshore region and physiographic features noted in this paper.

Figure 2. Map showing location of high-resolution seismic-reflection profile track lines (solid lines) and vibracore stations (dots).

Figure 3. Seismic-reflection record from Cape Cod Bay showing pre-Mesozoic basement rocks (Pz) overlain by coastal plain/continental shelf strata (Tcp) of Tertiary age, glacial drift (Ql and Wld) of late Pleistocene age, and quiet-water marine deposits (Qm) of Holocene age. Reflector mu is post-glacial marine unconformity. Location of seismic record is shown in Figure 2 (heavy bar).

Figure 4. Seismic-reflection record and interpretive section from eastern Rhode Island Sound showing deeply eroded coastal plain/continental shelf strata (Ku) of mostly Late Cretaceous age overlain by glacial drift (Qod and Qdo) of Late Pleistocene age, and estuarine (Qfe) and marine (Qm) deposits of Holocene age. Location of seismic record is shown in Figure 2 (heavy bar).

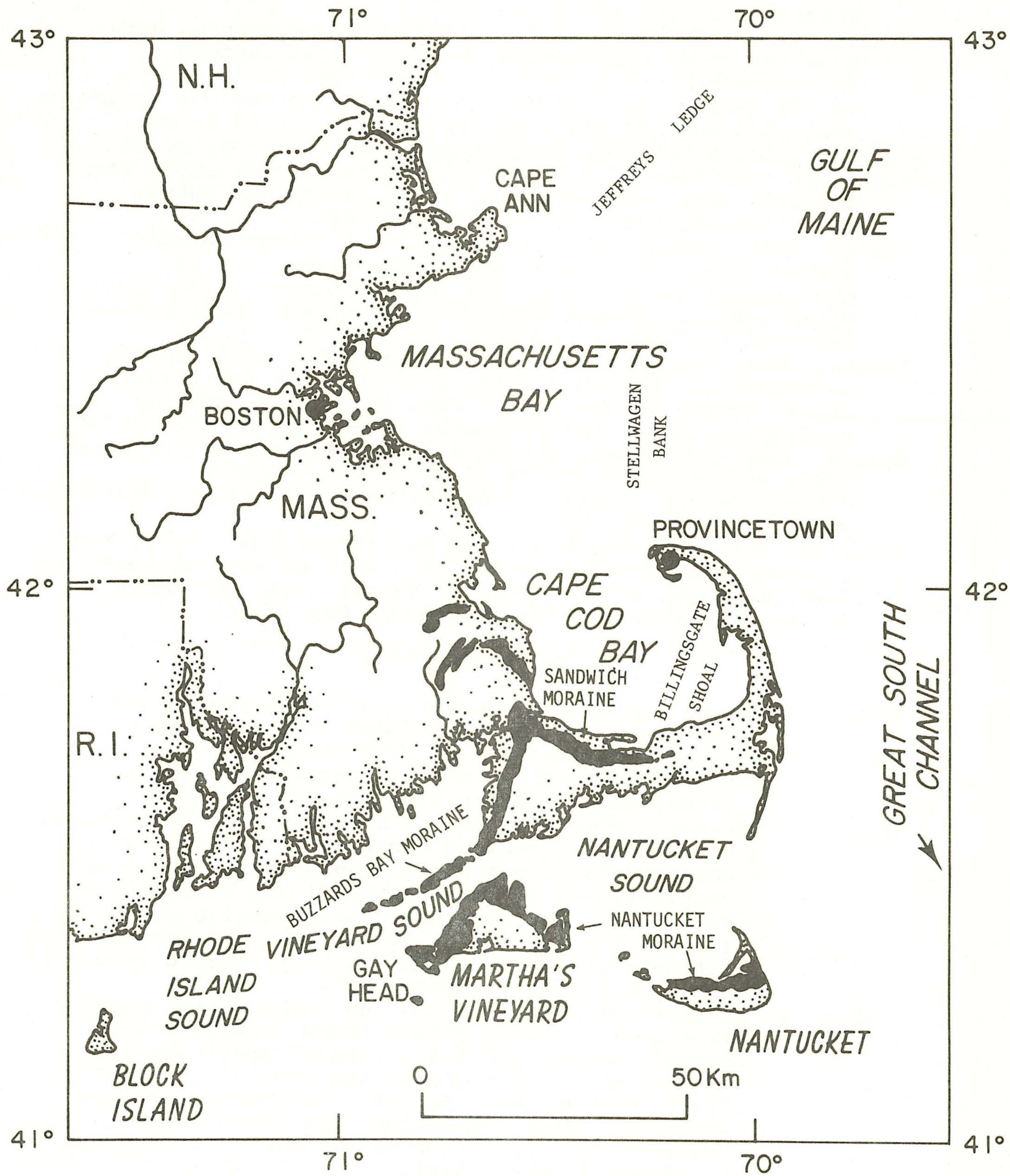
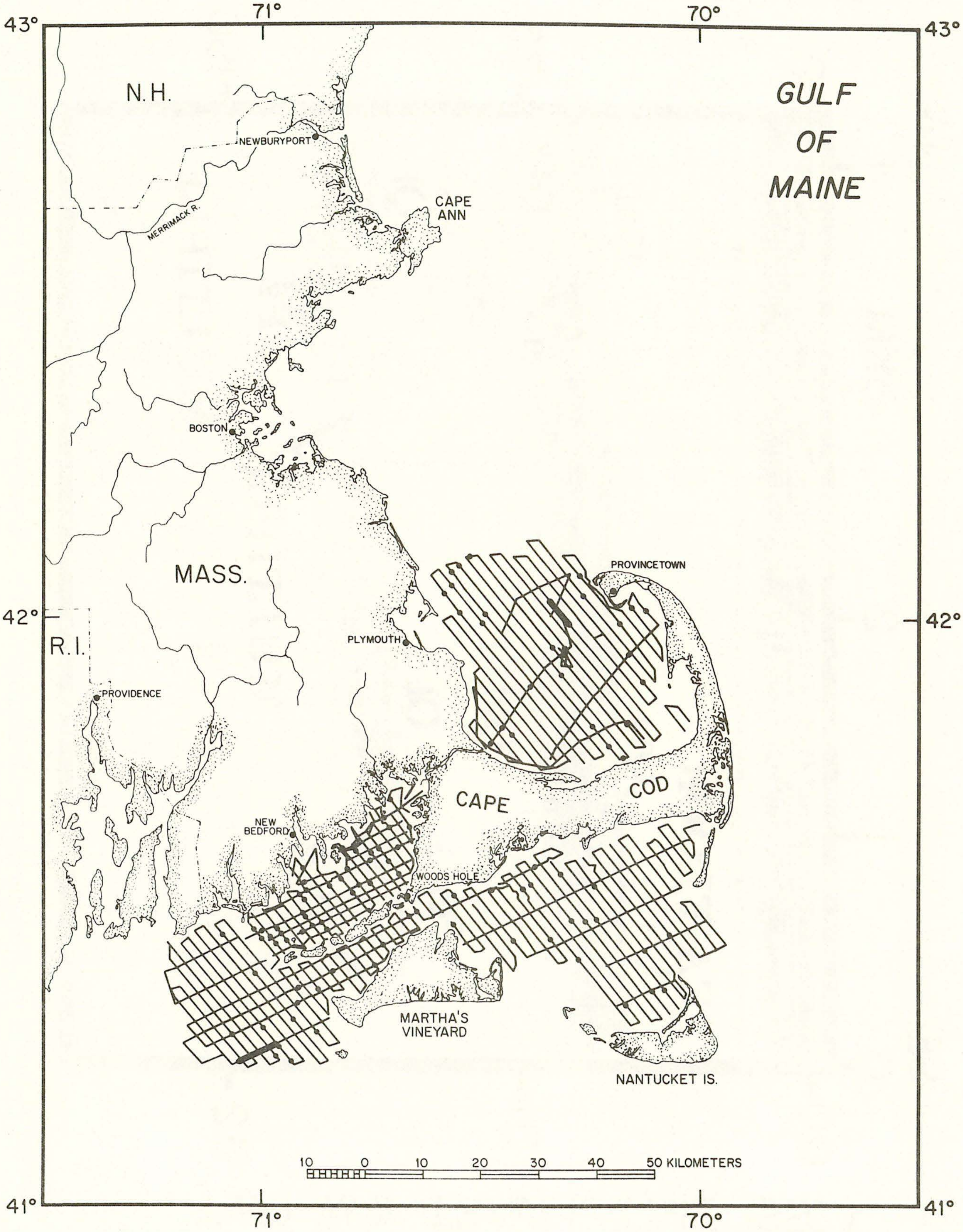
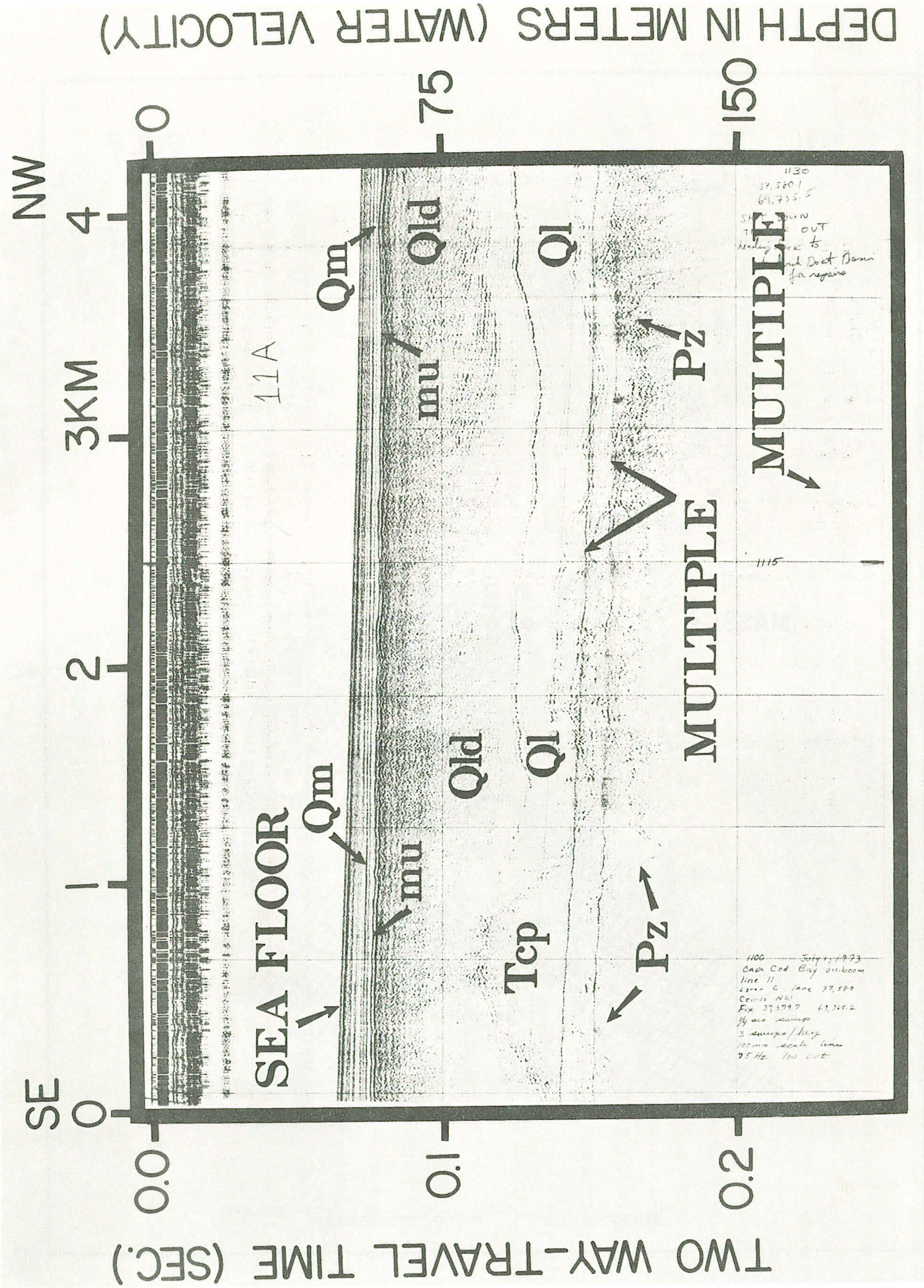

71°
70°
43°
43°
N.H.
JEFFREYS LEDGE
CAPE ANN
GULF OF MAINE
MASSACHUSETTS BAY
BOSTON
STELLWAGEN BANK
MASS.
PROVINCETOWN
42°
42°
CAPE COD BAY
BILLINGSGATE SHOAL
SANDWICH MORAINE
GREAT SOUTH CHANNEL
R.I.
BUZZARDS BAY MORAINE
NANTUCKET SOUND
VINEYARD SOUND
NANTUCKET MORAINE
RHODE ISLAND SOUND
GAY HEAD
MARTHA'S VINEYARD
NANTUCKET
BLOCK ISLAND
0
50Km
41°
41°
71°
70°

Figure 1.



43°
71°
70°
43°
N.H.
GULF
OF
MAINE
NEWBURYPORT
CAPE
ANN
MERRIMACK R.
BOSTON
MASS.
PROVINCETOWN
42°
42°
R.I.
PLYMOUTH
PROVIDENCE
CAPE
COD
NEW
BEDFORD
WOODS HOLE
MARTHA'S
VINEYARD
NANTUCKET IS.
10
0
10
20
30
40
50 KILOMETERS
41°
71°
70°
41°

Figure 2.



DEPTH IN METERS (WATER VELOCITY)
0
75
150
NW
SE
0
1
2
3KM
4
TWO WAY-TRAVEL TIME (SEC.)
0.0
0.1
0.2
11A
SEA FLOOR
Qm
mu
Qld
Ql
Tcp
Pz
MULTIPLE

Figure 3.

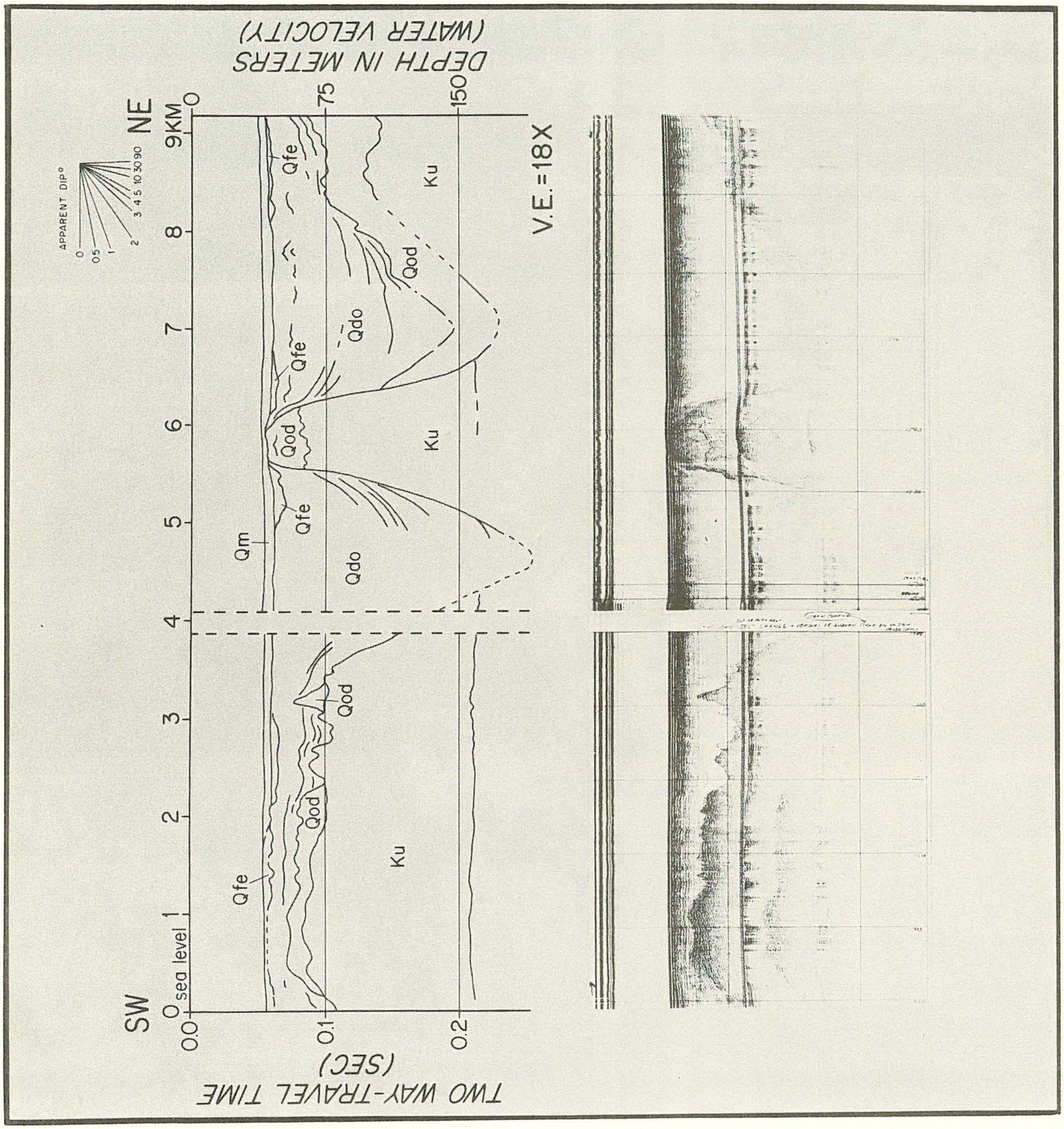

SW
NE
0 sea level
1
2
3
4
5
6
7
8
9KM
0.0
0.1
0.2
TWO WAY-TRAVEL TIME (SEC)
0
75
150
DEPTH IN METERS (WATER VELOCITY)
APPARENT DIP°
V.E.=18X
Qm
Qfe
Qod
Qdo
Ku

Figure 4.

FINE SEDIMENT ERODIBILITY IN INNER-SHELF ENVIRONMENTS

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(Synopsis by D.G. Aubrey)

Investigators at M.I.T. have been studying many aspects of sediment transport, both in the laboratory and the field. Recently, a field and laboratory study of the erosion of fine-grained marine sediments was completed by Young and Southard (1978). A study by Scott Briggs and John Southard is nearly completed in Vineyard Sound, investigating the migration rates and behavior of a sand wave field. Other studies covering various aspects of sediment transport are underway.

REFERENCE

Young, R.A. and J.B. Southard, 1978, Erosion of fine-grained marine sediments: sea-floor and laboratory experiments. GSA Bulletin, V. 89, p. 663-672.

UNDERGRADUATE COASTAL PROJECTS AT BOSTON STATE COLLEGE

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Synopsis by D.G. Aubrey

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Over the past decade, the undergraduate classes in the Department of Regional Studies at Boston State College have undertaken class projects on coastal geomorphology. The following is a list of the projects which have been completed to this time.

No. 1 Association Beach, Plymouth, Mass.; A Geomorphological Study, Class Project, Boston, Boston State College, 1972.

No. 2 Yirell Beach, Winthrop, Mass.; A Geomorphological Study Class, Project, T.V. Tape, Boston, Boston State College, 1973.

No. 3 Rainsford Island, Boston Harbor; A Geomorphological Study, Class Project, Slide-Tape form, Boston, Boston State College, 1974.

No. 4 Fourth Cliff, Scituate, Mass.; A Geomorphological Study, Class Project, Boston, Boston State College, 1975.

No. 5 Shingle Beach, Scituate, Mass.; A Geomorphological Study, Class Project, Boston, Boston State College, 1977.

No. 6 Plum Island, Southern Terminus, Newburyport, Mass.; A Geomorphological Study, Class Project, Boston, Boston State College, 1978.

INSTRUMENTATION PROBLEMS IN THE COASTAL ZONE

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The tasks of a current measurement program in the coastal zone are 1) to adequately measure water transport in the presence of waves and 2) to measure the structure of the flow responsible for such effects as sediment transport and bottom friction. The water transport measurement task is a traditional one for current meters. In the coastal zone, the principal difficulty is reversing flow and short excursion lengths. The rotor-vane meters of the VACM type, and even more so the propellor-vane meters of the Aanderaa type fail to respond to reversals with excursions near the vane response length, and alias currents badly in some cases. The solution to this problem is to measure meter components along fixed x-y axes or relatively fixed axes, rather than r-θ components. Electromagnetic, acoustic, and fan-type current meters satisfy this requirement. However, none is entirely problem free. The EM and the acoustic meters each suffer from some zero drift, and each disturbs the flow somewhat, especially if the flow is not in the horizontal plane. The two axis fan current meters have a good cosine response, but in return for an accurate zero point, have a threshold of flow below which they stall. If waves are present, this threshold effect may be negligible, but inertial effects may intrude. Finally each sensor is more or less susceptible to fouling and the fan current meters are somewhat fragile. The vector average of a wave measured at a fixed height off the bottom is not the same as transport, because the depth of the water varies as the troughs and crests pass. Corrections require wave height information which is generally lost in the vector average. Otherwise, the situation is not bad and even rotor-vane instruments do pretty well much of the time.

The second task requires the 3-d measurement of current at an array of points. The important results of these measurements are cross products such as Reynolds stress and spectral information from the time series. Thus, either high data rates or in-situ processing and recording of reduced data sets is implied. If the former, short experiments are required. If the latter, advanced knowledge of the important terms is required.

The sensor must be capable of accurately resolving the flow in 3 dimensions. For non-reversing flows, arrays of small propellors have performed well. EM 3-D sensors have been used, although they create a certain amount of flow disturbance. We have developed acoustic current meter arrays that resolve the current well. One version is satisfactory for bidirectional flow and another for omnidirectional flow. The data problem limits the sampling rate which in turn sets a lower limit on the sample volume. In our case, we use 1.3 Hz and 15 cm for steady currents and will step the sample rate up to 7 Hz for waves. Our sensors are rings containing piezoelectric transducers that measure the flow component along oblique paths to avoid measuring in the wake of the axes. Four axes are measured to permit rejecting an axis that lies close to the flow direction yet retain the 3-D vector. Each axis is measured twice, with the electronics interchanged between transducers between measurements. This allows zero drift to be removed in processing. However, the exact value of the zero current measurement must be obtained for each experiment by placing bags over the sensors to stop the flow.

For each sensor the analysis consists of orthogonalizing the flow into u, v, and w coordinates in the sensor frame. Then, for short pieces (12 minutes has worked for Vineyard Sound), the coordinates are releveled to give u', v', and w' where $\overline{w}'=\overline{v}'=o$. Then $\overline{u'w'}$ for the interval is computed.

An array of 4 sensors at 1/4 m, 1/2 m, 1m, and 2m has been used to profile the boundary layer. The deviations of the stress profile from constant, or even linear, reflects the effect of bottom topography. At any single location, the flow may be accelerated by bumps, a slope of only a few degrees changing the stress over the height of the bump by a factor of two. The stress on the sediment at a single location in the absence of waves is the shear stress at the bottom of the water column which will be most nearly represented by the Reynolds stress at the lowest sensor. However, this is least representative of the horizontally averaged stress. The more distant sensor, above the topography, is best able to represent that. We hope to use horizontal arrays, as well as vertical arrays for our experiments in the future.

In the wave boundary layer, the scales are smaller than the ACM sensors. For this region, we have turned to the Laser Doppler Velocimeter (LDV) which measures the velocity of particles which scatter light in a tiny volume. We are adapting a single axis prototype for this task now. We must be content with adding a single axis (selectable) measurement within the ripple height to the profile of velocity and stress above.

Dissipation scale measurements with LDV or hot wire probes present special problems. The hot wire probe is subject to contamination though it may not be too bad, if the probe is made right. The LDV produces a complex signal that requires sophisticated processing. Each has a very high data rate. Fortunately, there is reason to believe only a short record is needed to supplement larger scale measurements.

Ultimately, the greatest problem of current process measurements may be the representativeness of point measurements. Friction is the average of the stress, but erosion occurs at a single point on a roughness element.

March 1979

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16. Abstracts

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Refer to page 1 for abstract.

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